Analysis and Backcalculation for Pavement Structures

Kunihito Matsui
Tokyo Denki University

1. Static Analysis

1-1. Cylindrical coordinates

- The Software GAMES is compared with BISAR

1-2. Cartesian coordinates

- The uniform loads over a rectangular area and a circular area are compared

2. Dynamic Analysis

Wave propagation in viscoelastic multilayered media

- The responses from the solutions are compared with the results of ADINA

3. Backcalculation

Dynamic backcalculation

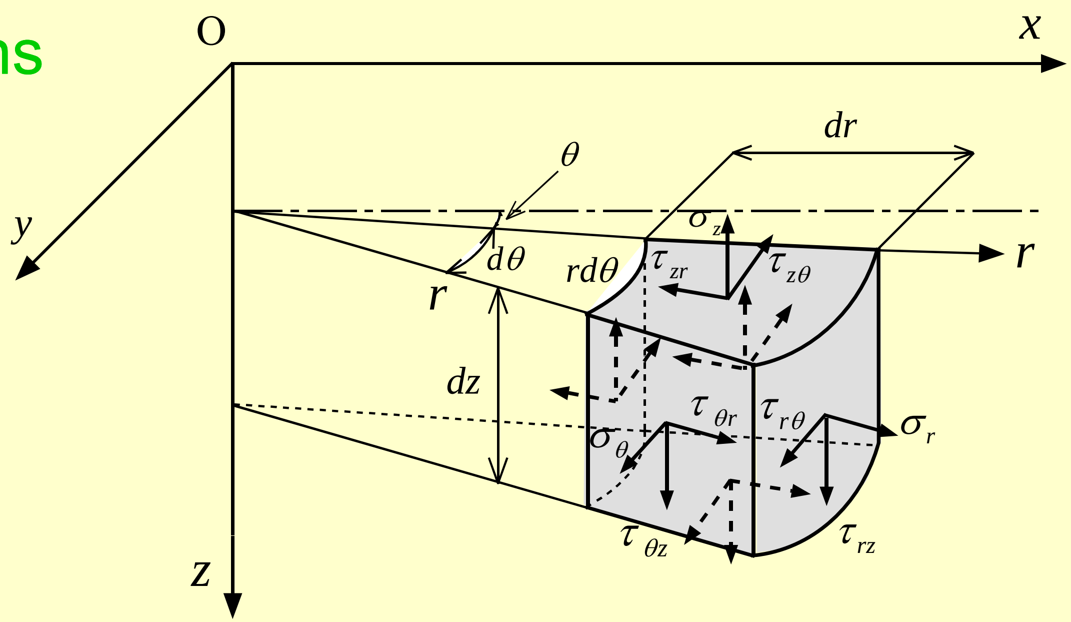
1. Static Analysis in Cylindrical Coordinates

The equilibrium equations

$$\frac{\partial \sigma_r}{\partial r} + \frac{1}{r}\frac{\partial \tau_{r\theta}}{\partial \theta} + \frac{\partial \tau_{rz}}{\partial z} + \frac{\sigma_r - \sigma_\theta}{r} = 0$$

$$\frac{\partial \tau_{r\theta}}{\partial r} + \frac{1}{r}\frac{\partial \sigma_\theta}{\partial \theta} + \frac{\partial \tau_{\theta z}}{\partial z} + \frac{2\tau_{r\theta}}{r} = 0$$

$$\frac{\partial \tau_{rz}}{\partial r} + \frac{1}{r}\frac{\partial \tau_{\theta z}}{\partial \theta} + \frac{\partial \sigma_z}{\partial z} + \frac{\tau_{rz}}{r} = 0$$



Strain-Displacement

$$\varepsilon_r = \frac{\partial u}{\partial r}; \quad \gamma_{r\theta} = \frac{1}{r}\frac{\partial u}{\partial \theta} + \frac{\partial v}{\partial r} - \frac{v}{r}$$

$$\varepsilon_\theta = \frac{u}{r} + \frac{1}{r}\frac{\partial v}{\partial \theta}; \quad \gamma_{\theta z} = \frac{1}{r}\frac{\partial w}{\partial \theta} + \frac{\partial v}{\partial z}$$

$$\varepsilon_z = \frac{\partial w}{\partial z}; \quad \gamma_{zr} = \frac{\partial w}{\partial r} + \frac{\partial u}{\partial z}$$

Strain-Stress

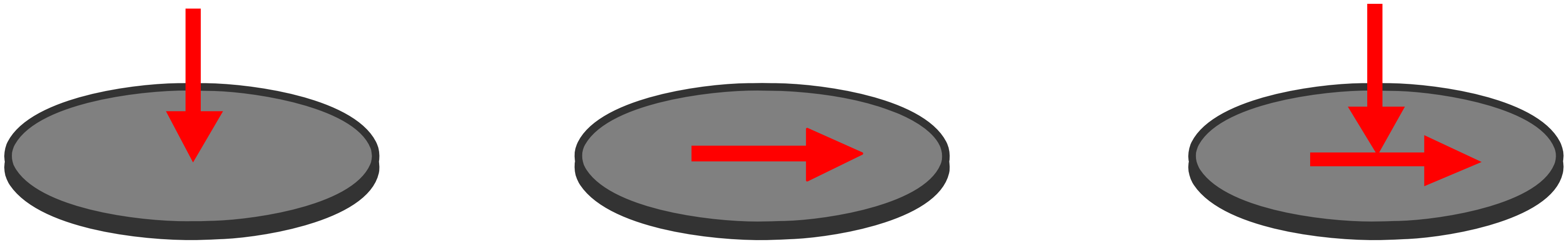
$$\varepsilon_r = \frac{1}{E}\left(\sigma_r - \nu\sigma_\theta - \nu\sigma_z\right); \; \gamma_{r\theta} = \frac{2(1+\nu)}{E}\tau_{r\theta}$$

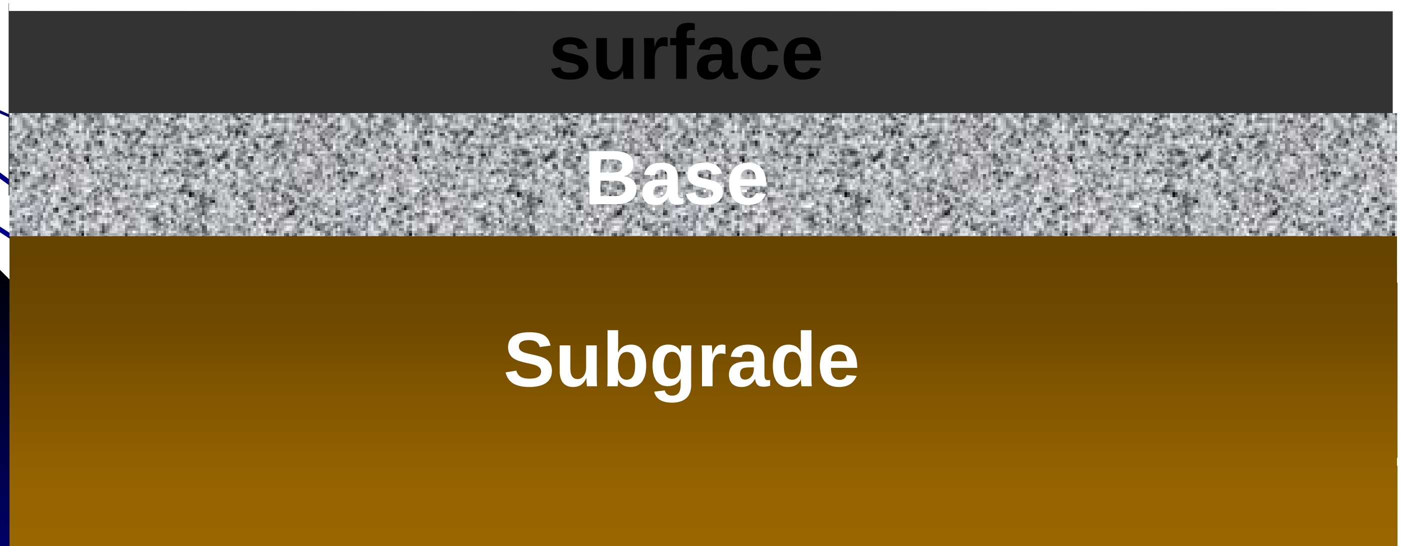
$$\varepsilon_\theta = \frac{1}{E}\left(\sigma_\theta - \nu\sigma_z - \nu\sigma_r\right); \; \gamma_{\theta z} = \frac{2(1+\nu)}{E}\tau_{\theta z}$$

$$\varepsilon_z = \frac{1}{E}\left(\sigma_z - \nu\sigma_r - \nu\sigma_\theta\right); \; \gamma_{zr} = \frac{2(1+\nu)}{E}\tau_{zr}$$

Uniformly distributed circular load

Vertical load | Horizontal load | vertical + horizontal loads



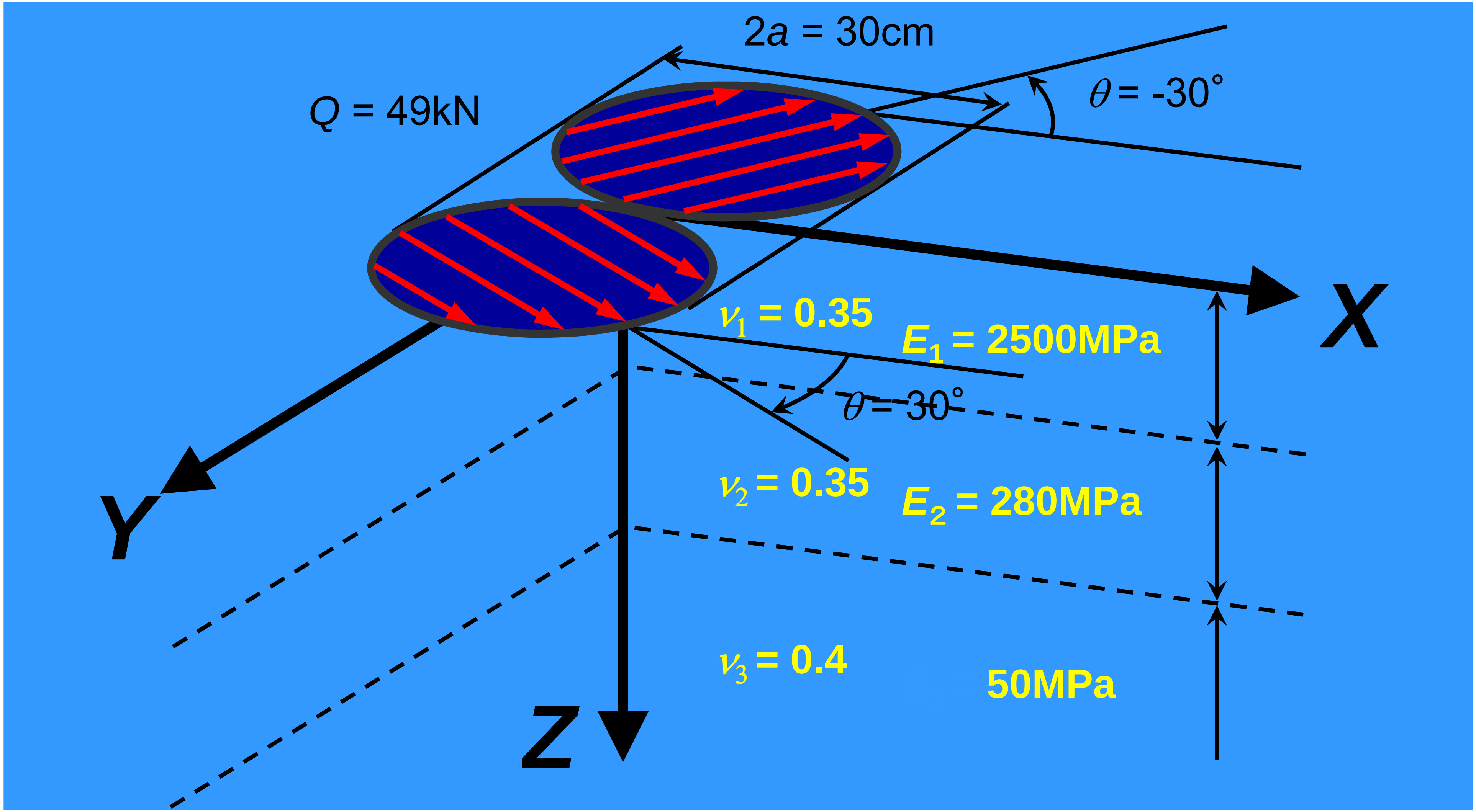


Features of GAMES

- **Pavement:** Multilayer pavement system with a possibility of interface slip.
- **Surface load:** Multiple vertical and/or horizontal circular loads.
- **Analysis:** Multiple points of interest.
- **Response:** Stresses, strains, and displacements

1. Static Analysis

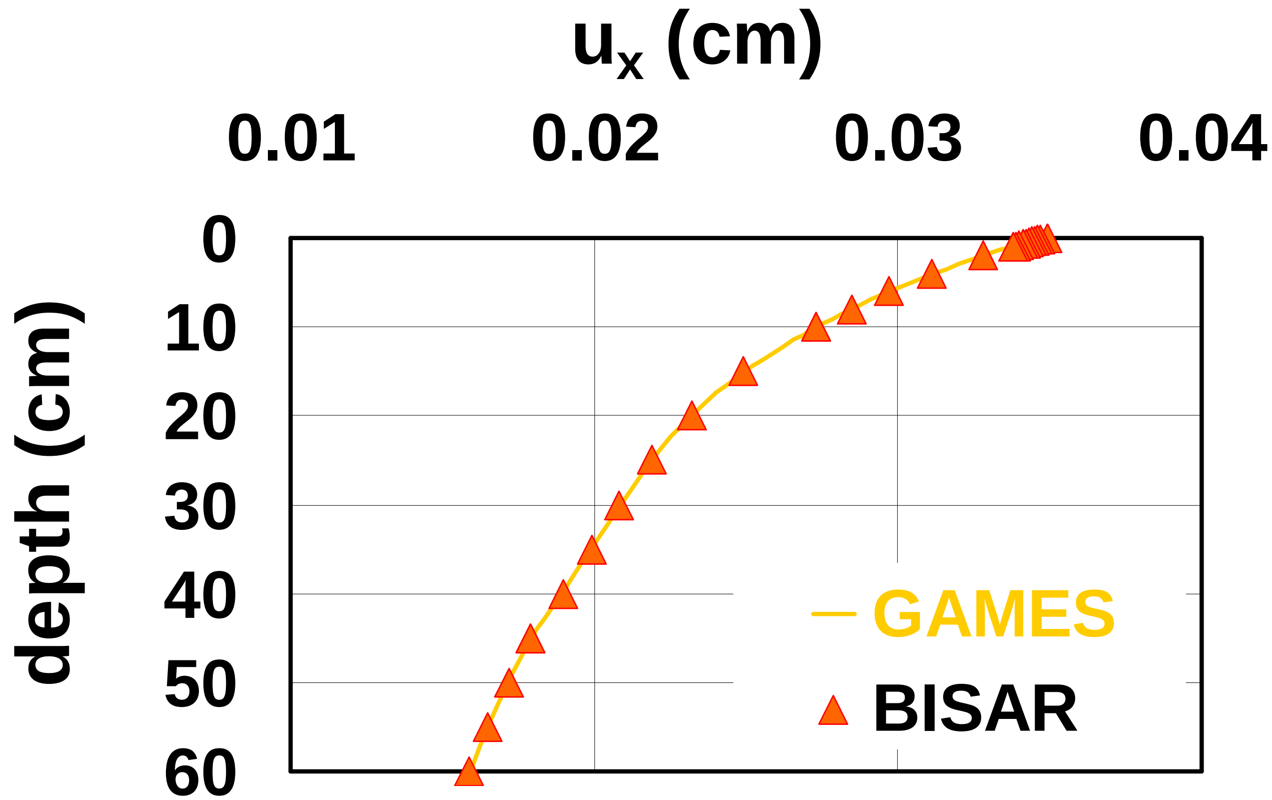
GAMES vs BISAR



1. Static Analysis

GAMES vs BISAR

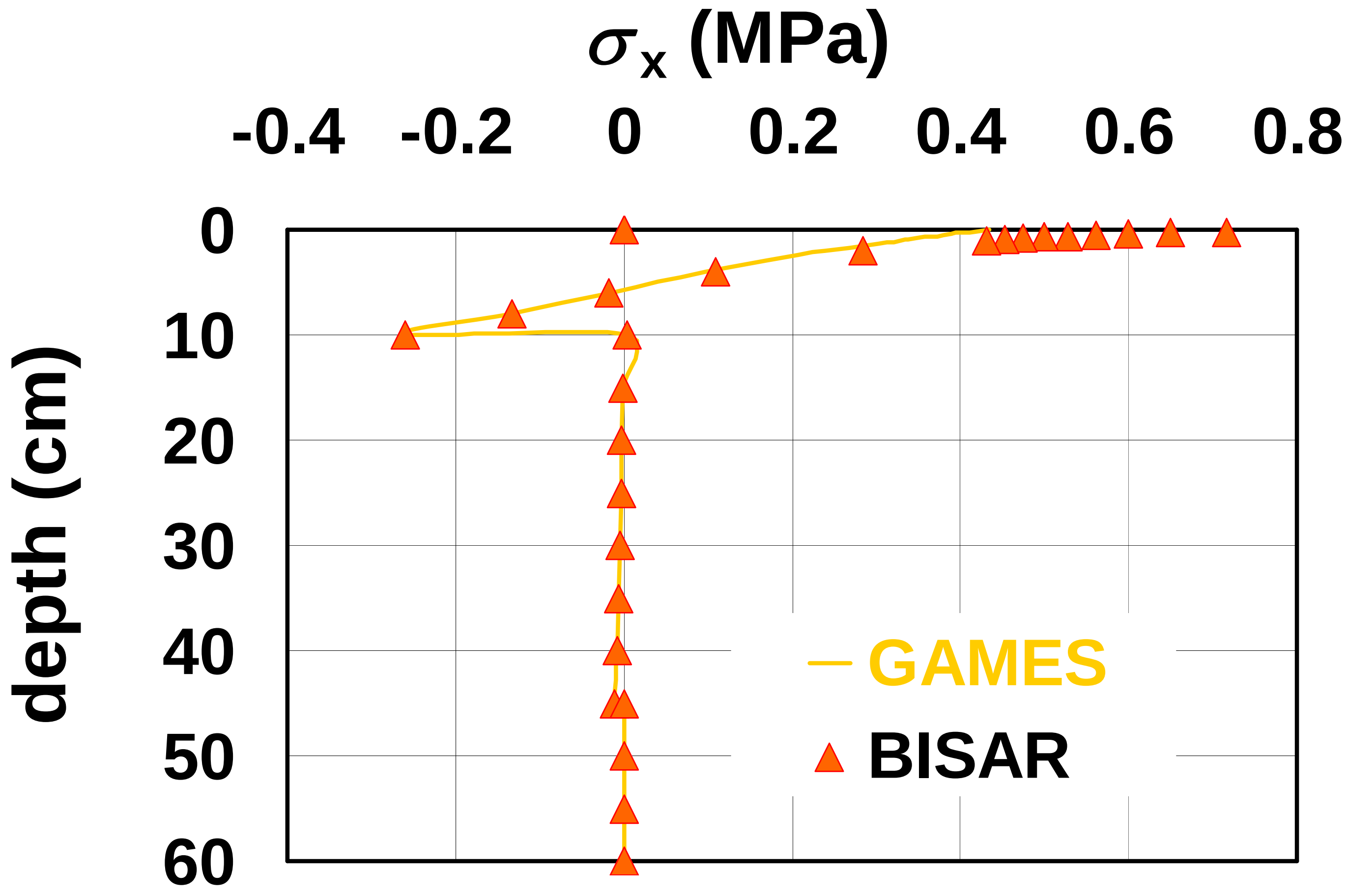
~ Distribution of horizontal displacement, u_x ~



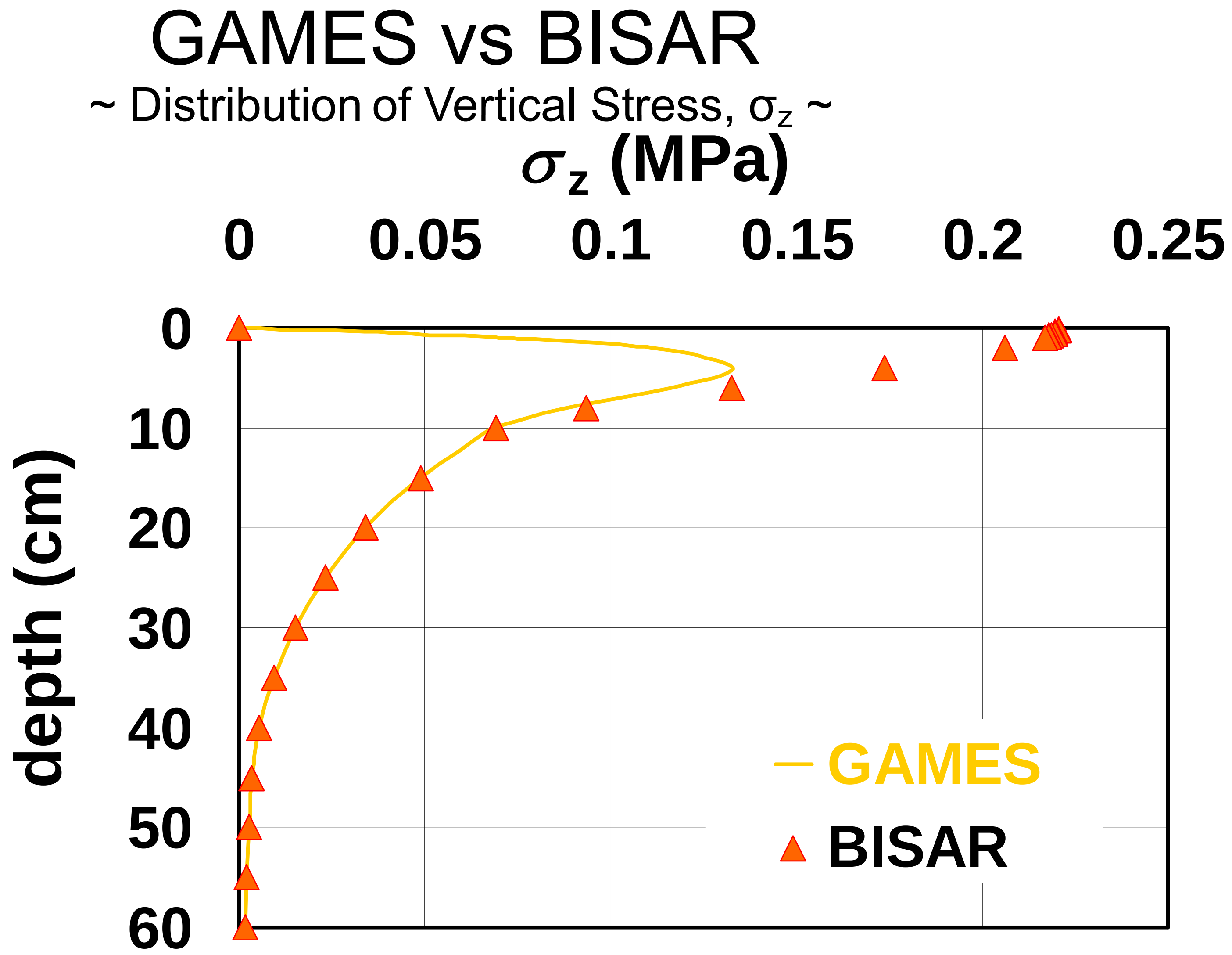
1. Static Analysis

GAMES vs BISAR

~ Distribution of horizontal Stress, σ_x ~



1. Static Analysis



Interface Slip Models

$$(1-\alpha_i)\left\{u_r^i(h_i)-u_r^{i+1}(0)\right\}=\alpha_i\beta_i\tau_{rz}^i(h_i)$$

Model 1(GAMES) : $\beta_i = b^*\left(\frac{1+\nu_i}{E_i}+\frac{1+\nu_{i+1}}{E_{i+1}}\right)$

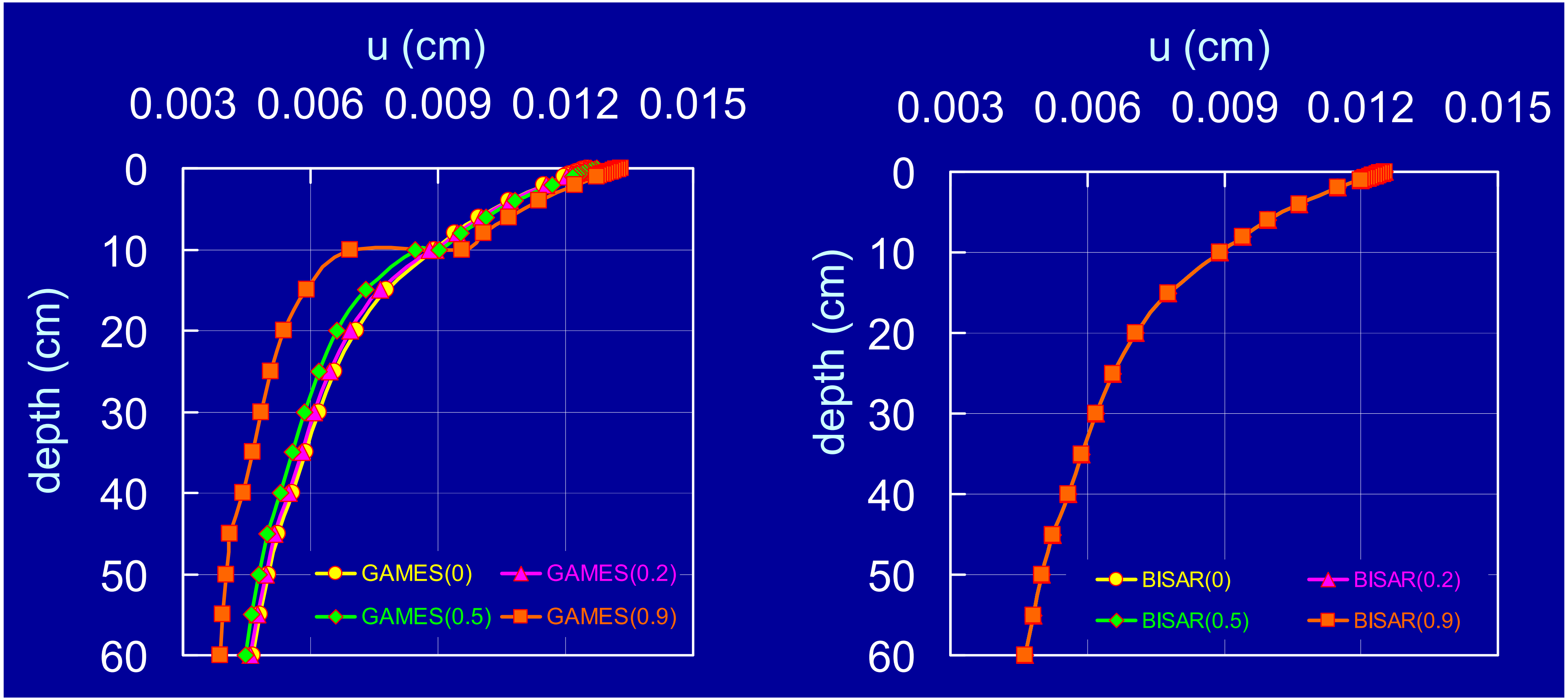
Model 2(BISAR) : $\beta_i = 2b^*\left(\frac{1+\nu_i}{E_i}\right)$

Model 3 : $\beta_i = 2b^*\sqrt{\left(\frac{1+\nu_i}{E_i}\right)\left(\frac{1+\nu_{i+1}}{E_{i+1}}\right)}$

$0 \le \alpha_i < 1.0$ slip parameter

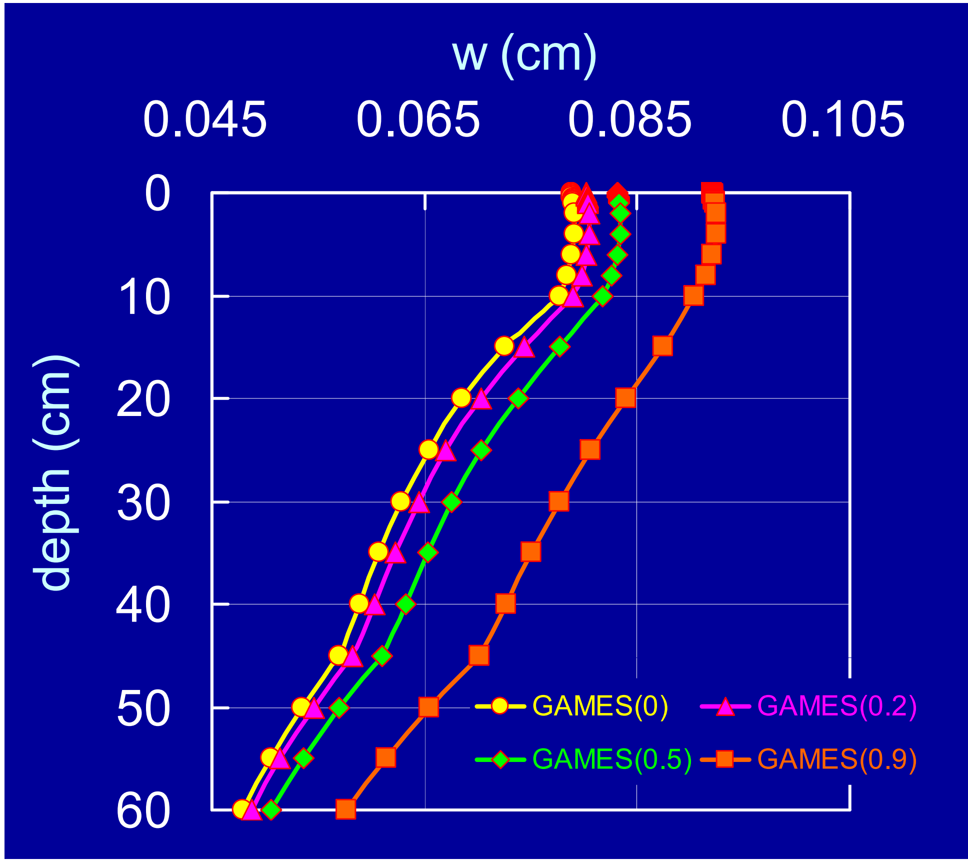
GAMES vs BISAR (Interface slip)

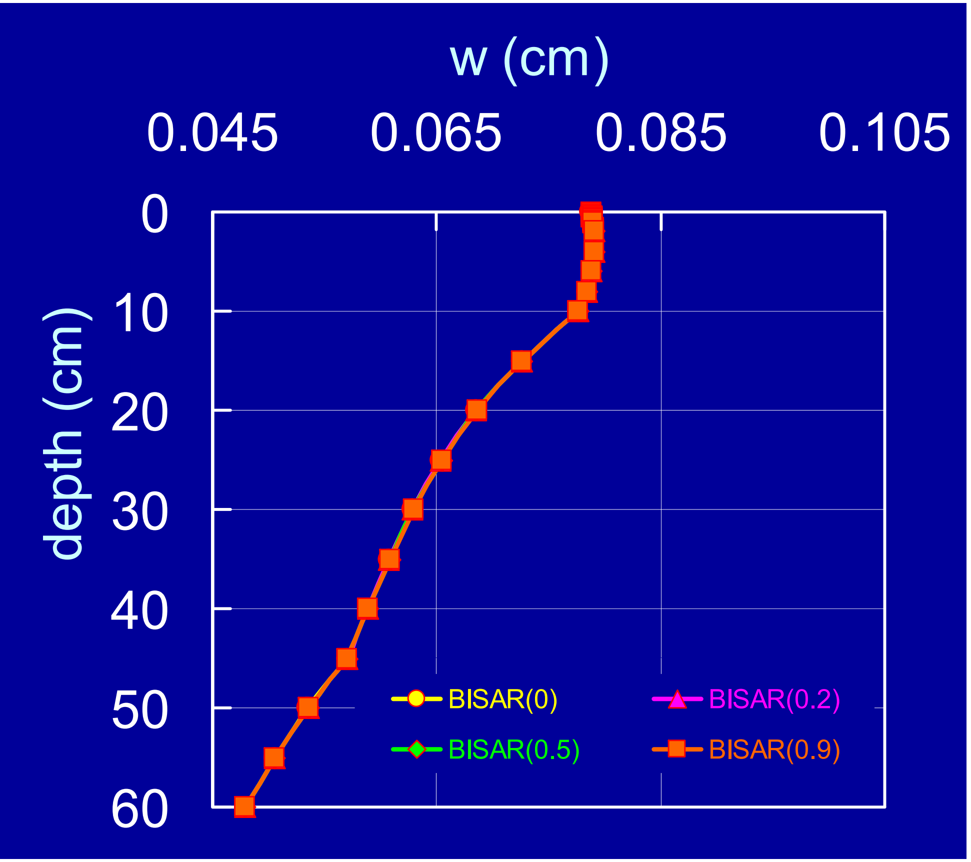
~ Distribution of radial displacement, u ~



GAMES vs BISAR (Interface slip)

~ Distribution of vertical displacement, w ~



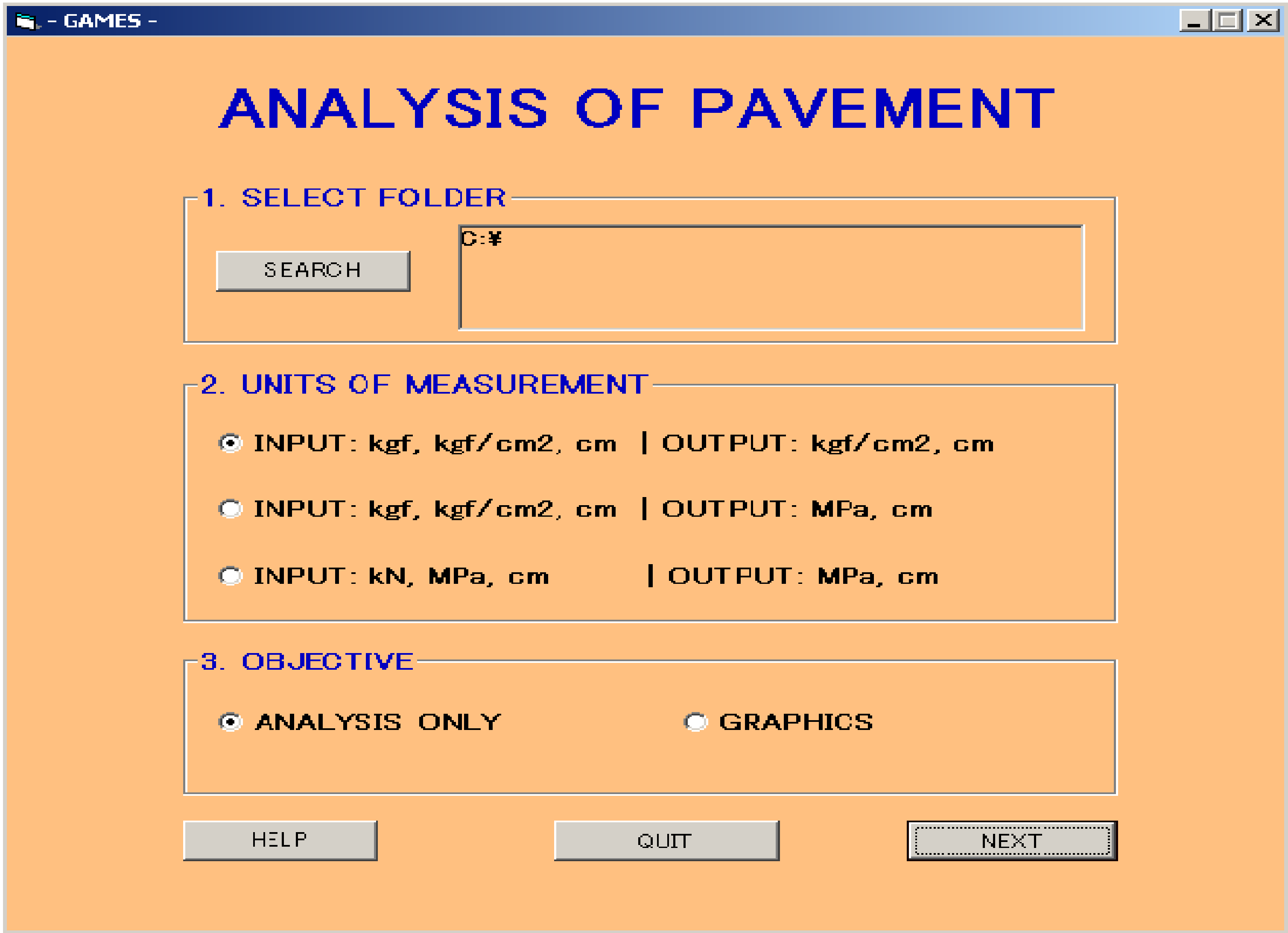


GAMES for Windows (graphics)
~ Features ~

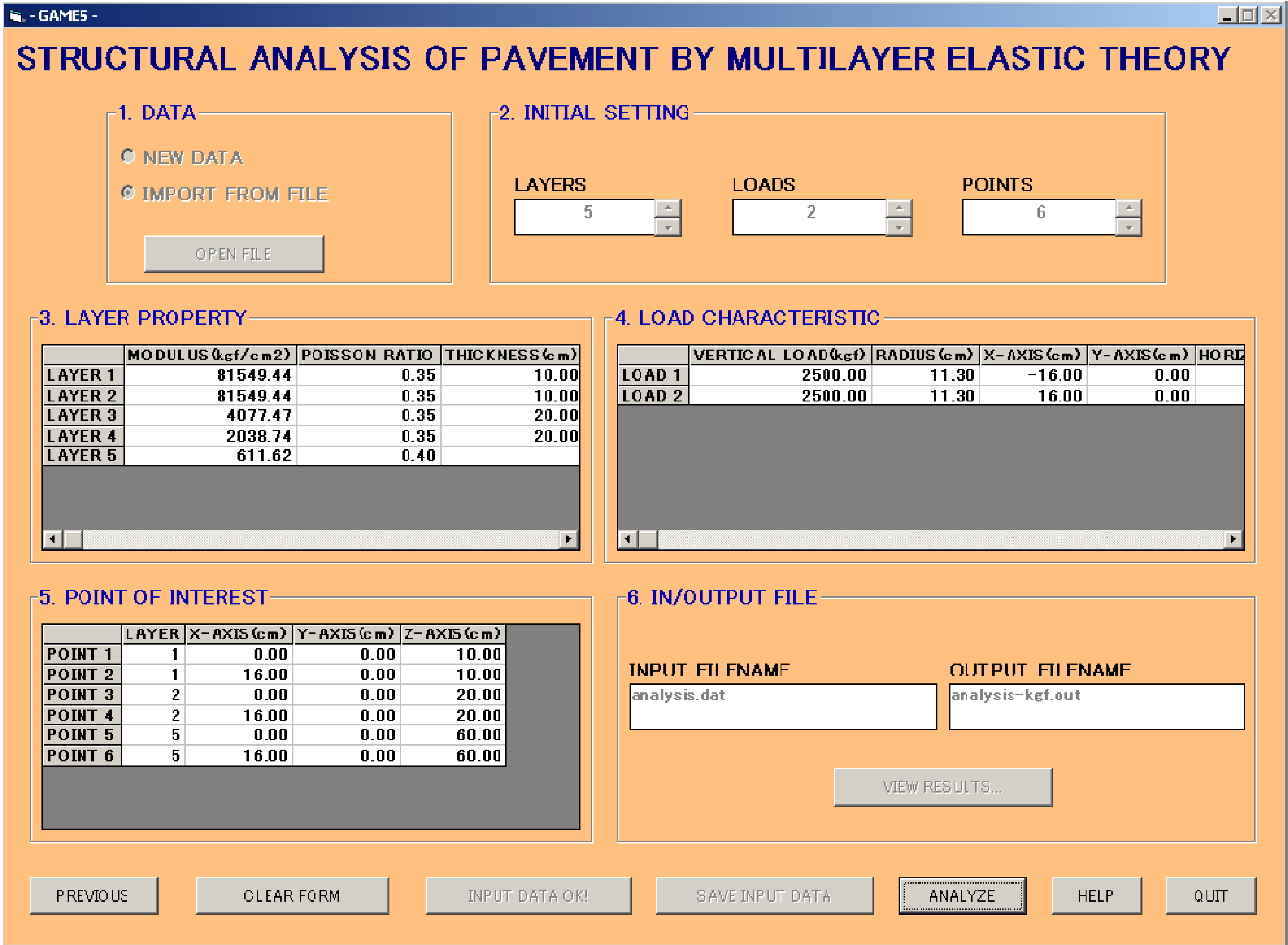
- Language: Japanese / English
- Unit of measurement: Load (kgf, kN), Length (cm), Elastic modulus (kgf/cm^2, MPa)
- Input: Input of new parameters or import from existing file
- Output：analytical results and graphics visualization (contour and color fill plots) of strain

GAMES for Windows
~ start-up window ~

GAMES for Windows
~ input window ~

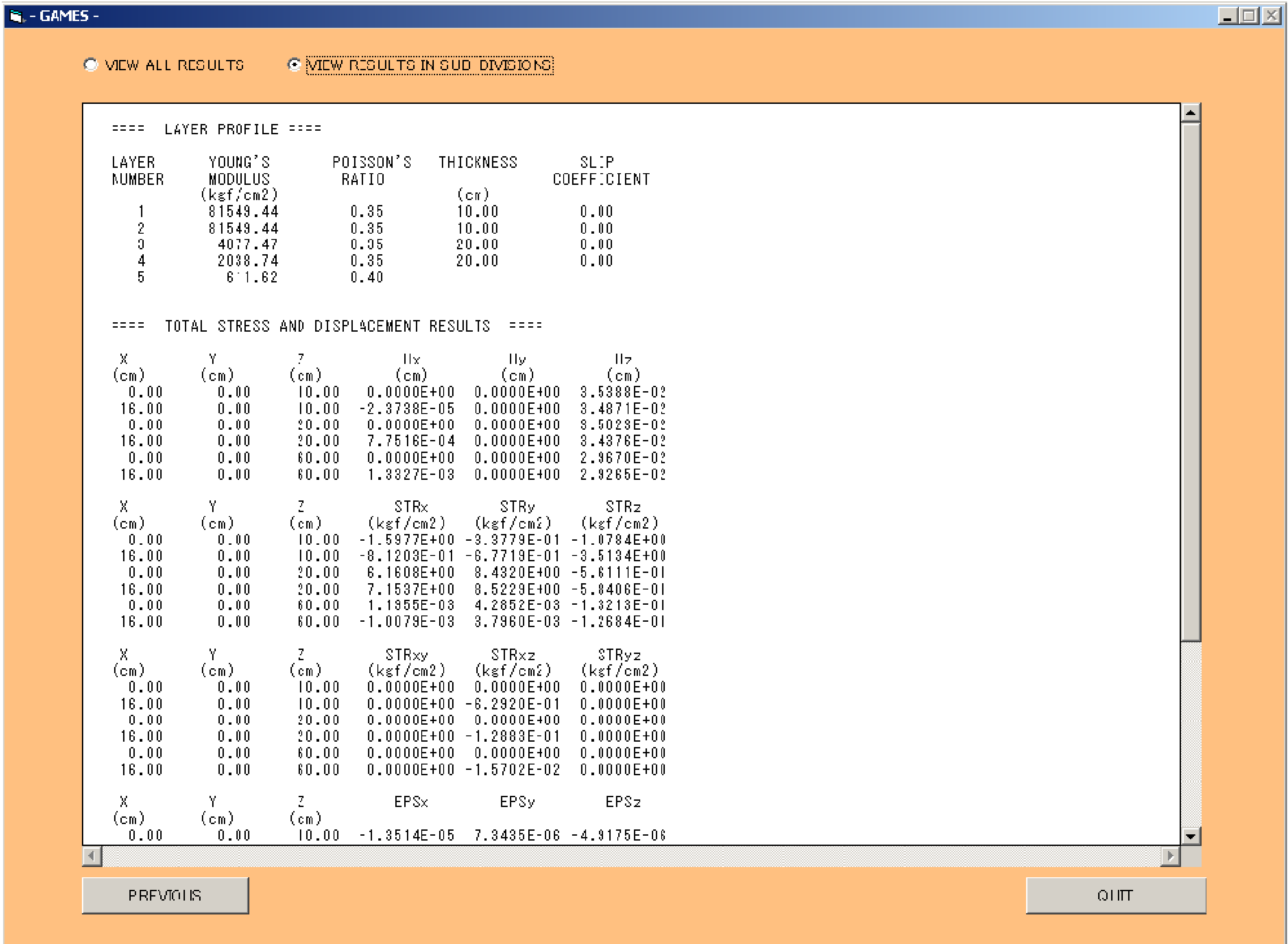


GAMES for Windows
~ input window ~



GAMES for Windows

~ output window ~



- GAMES -

VIEW ALL RESULTS — VIEW RESULTS IN SUD DIVISIONS

==== LAYER PROFILE ====

LAYER NUMBER	YOUNG'S MODULUS (kgf/cm2)	POISSON'S RATIO	THICKNESS (cm)	SL:P COEFF:CIENT
1	81549.44	0.35	10.00	0.00
2	81549.44	0.35	10.00	0.00
3	4077.47	0.35	20.00	0.00
4	2038.74	0.35	20.00	0.00
5	6[illegible]1.62	0.40		

==== TOTAL STRESS AND DISPLACEMENT RESULTS ====

X (cm)	Y (cm)	Z (cm)	Ux (cm)	Uy (cm)	Uz (cm)
0.00	0.00	10.00	0.0000E+00	0.0000E+00	3.5388E-02
16.00	0.00	10.00	-2.3738E-05	0.0000E+00	3.4871E-02
0.00	0.00	20.00	0.0000E+00	0.0000E+00	3.5023E-02
16.00	0.00	20.00	7.7516E-04	0.0000E+00	3.4376E-02
0.00	0.00	60.00	0.0000E+00	0.0000E+00	2.9670E-02
16.00	0.00	60.00	1.3327E-03	0.0000E+00	2.9265E-02

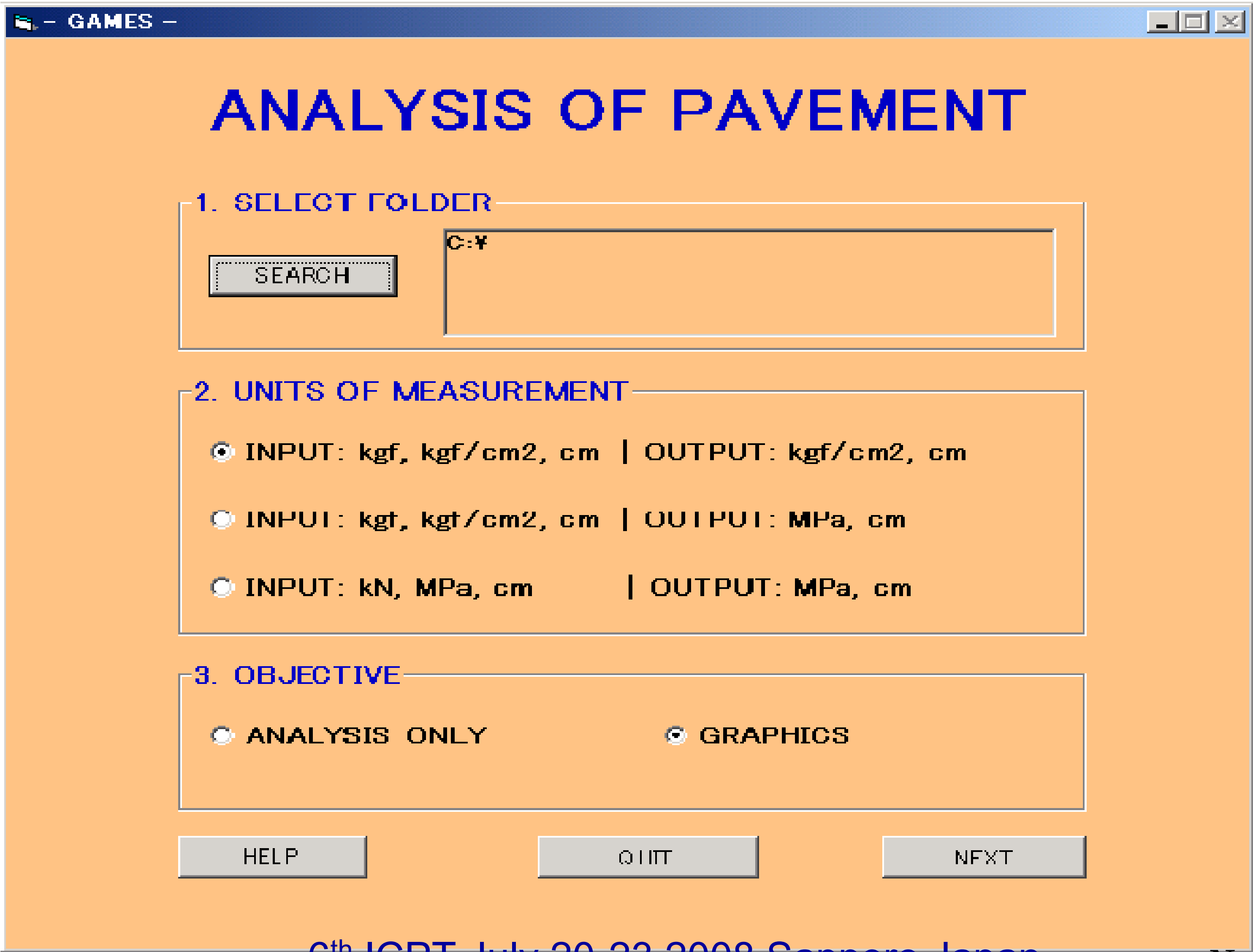
X (cm)	Y (cm)	Z (cm)	STRx (kgf/cm2)	STRy (kgf/cm2)	STRz (kgf/cm2)
0.00	0.00	10.00	-1.5977E+00	-3.3779E-01	-1.0784E+00
16.00	0.00	10.00	-8.1203E-01	-6.7719E-01	-3.5134E+00
0.00	0.00	20.00	6.1608E+00	8.4320E+00	-5.6111E-01
16.00	0.00	20.00	7.1537E+00	8.5229E+00	-5.8406E-01
0.00	0.00	60.00	1.1955E-03	4.2852E-03	-1.3213E-01
16.00	0.00	60.00	-1.0079E-03	3.7960E-03	-1.2684E-01

X (cm)	Y (cm)	Z (cm)	STRxy (kgf/cm2)	STRxz (kgf/cm2)	STRyz (kgf/cm2)
0.00	0.00	10.00	0.0000E+00	0.0000E+00	0.0000E+00
16.00	0.00	10.00	0.0000E+00	-6.2920E-01	0.0000E+00
0.00	0.00	20.00	0.0000E+00	0.0000E+00	0.0000E+00
16.00	0.00	20.00	0.0000E+00	-1.2883E-01	0.0000E+00
0.00	0.00	60.00	0.0000E+00	0.0000E+00	0.0000E+00
16.00	0.00	60.00	0.0000E+00	-1.5702E-02	0.0000E+00

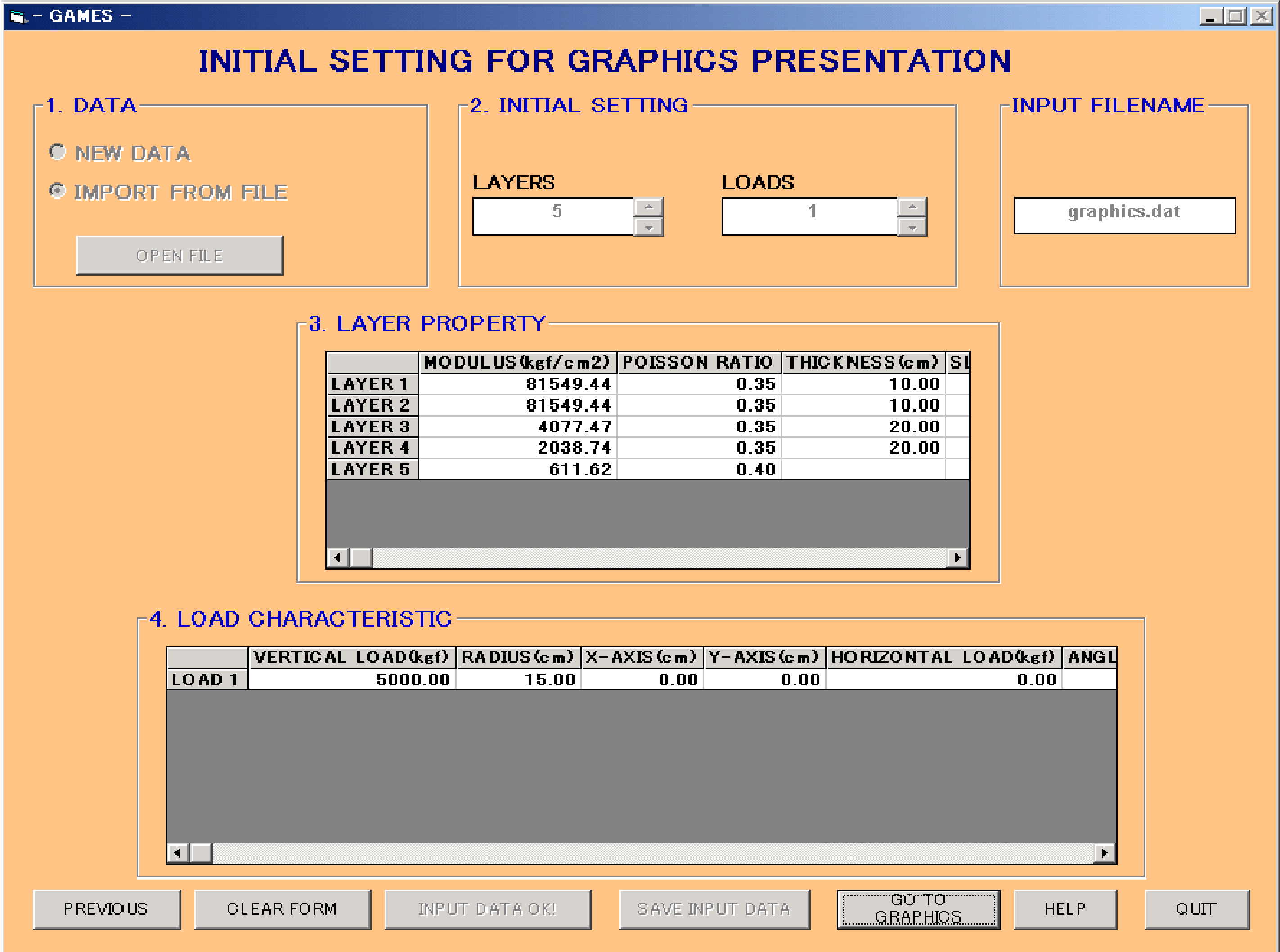
X (cm)	Y (cm)	Z (cm)	EPSx	EPSy	EPSz
0.00	0.00	10.00	-1.3514E-05	7.3435E-06	-4.9175E-06

PREVIOUS — QUIT

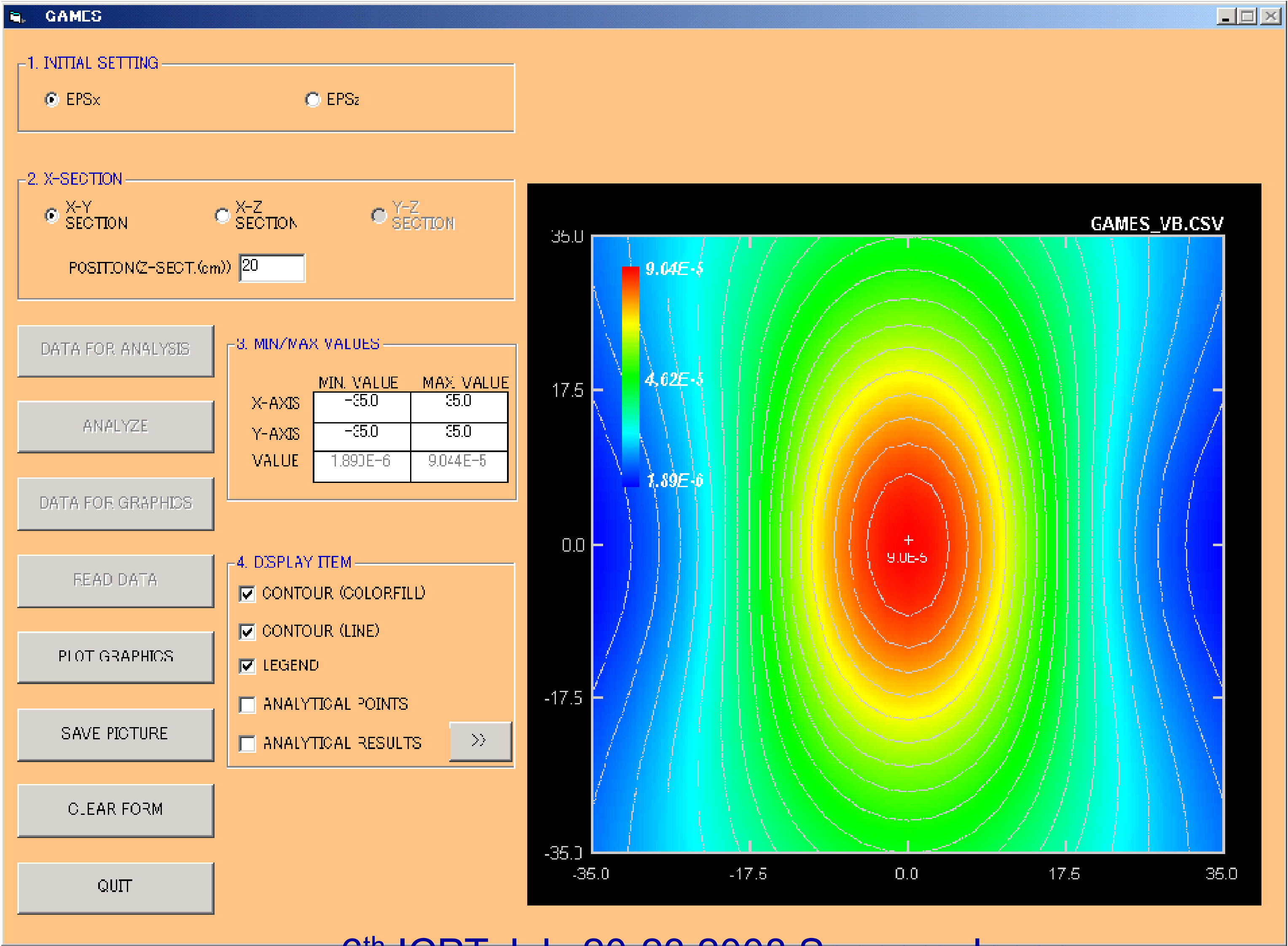
GAMES for Windows
~ input window ~



GAMES for Windows
~ input window ~



GAMES for Windows
~ output window ~

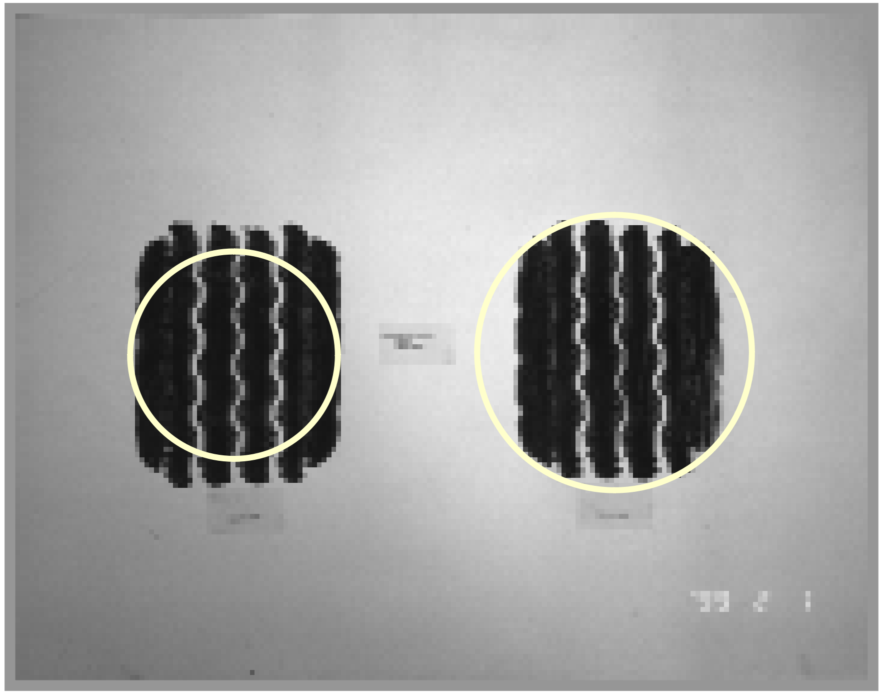


Summary and recommendations

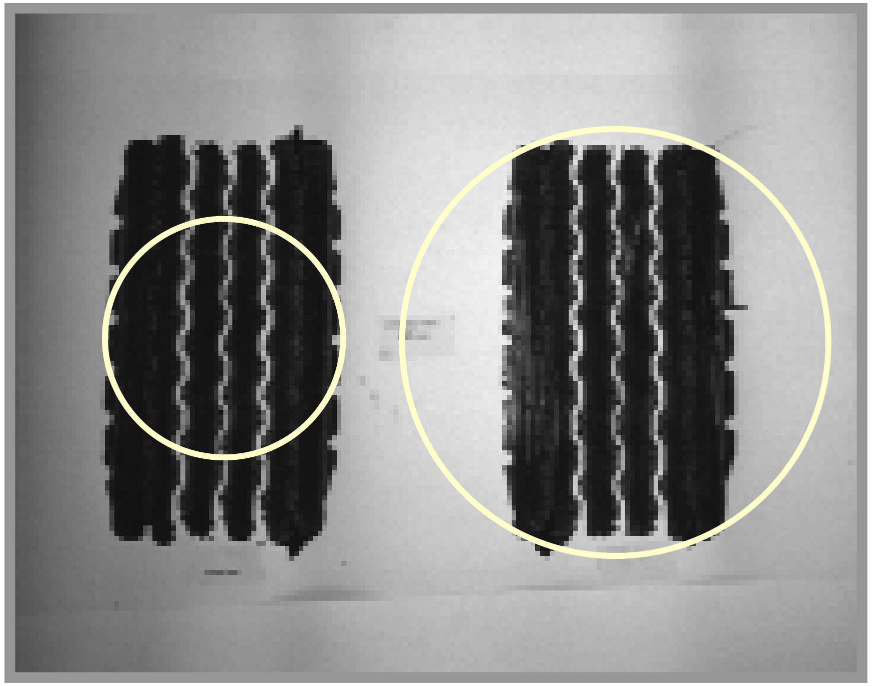
- Computational accuracy of GAMES
  - Accuracy of GAMES is similar to and in some cases better than BISAR.
- User interface and visualization process
  - Improves efficiency in the use of GAMES and assists users to visualize distribution of pavement responses.
- Application
  - GAMES can be used for analysis, evaluation and design of pavements.

Dual Tire Footprints by SIM (Stress In Motion)

(measured at CSIR, South Africa)

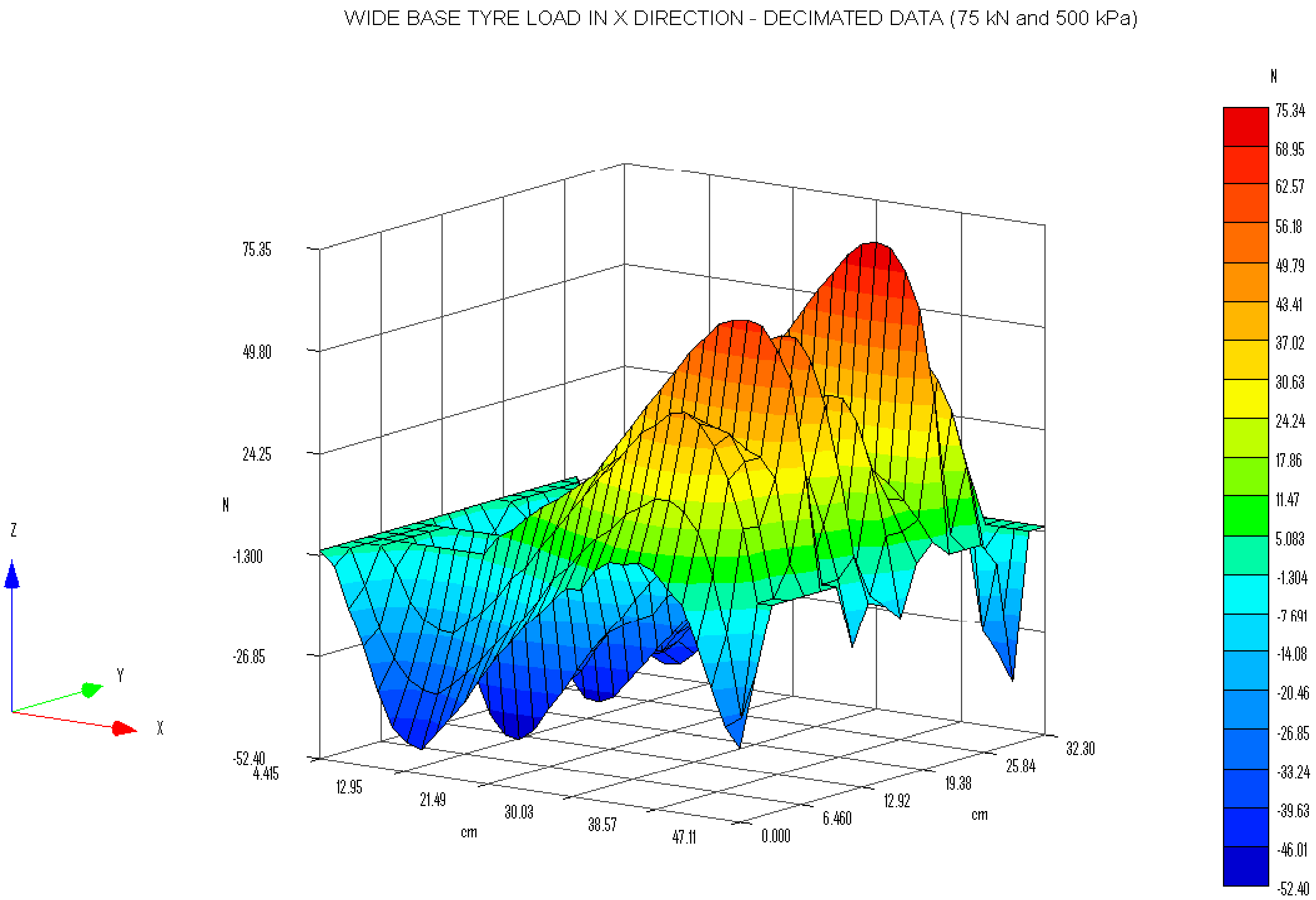


30 kN & 420 kPa inflation pressure

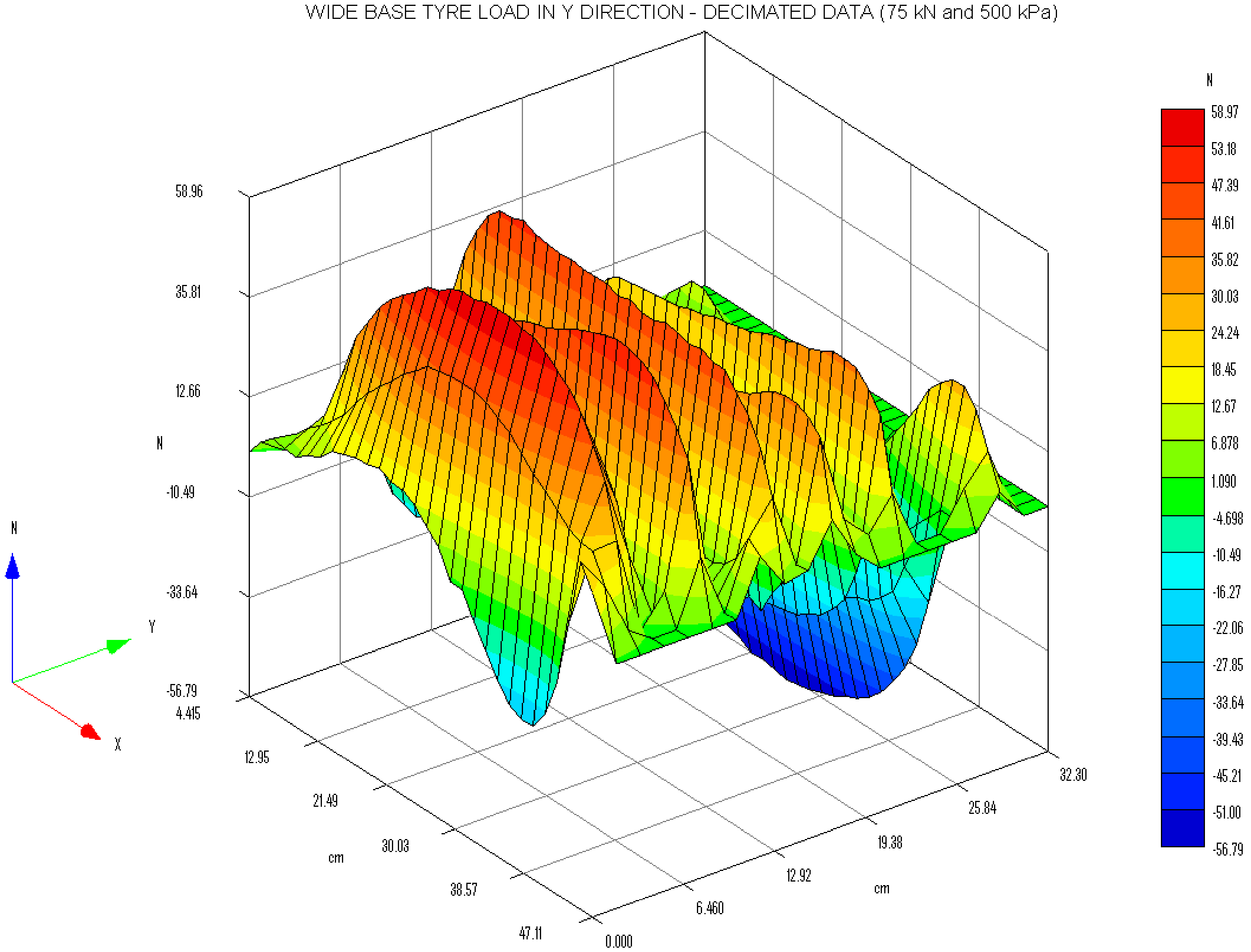


70 kN & 420 kPa inflation pressure

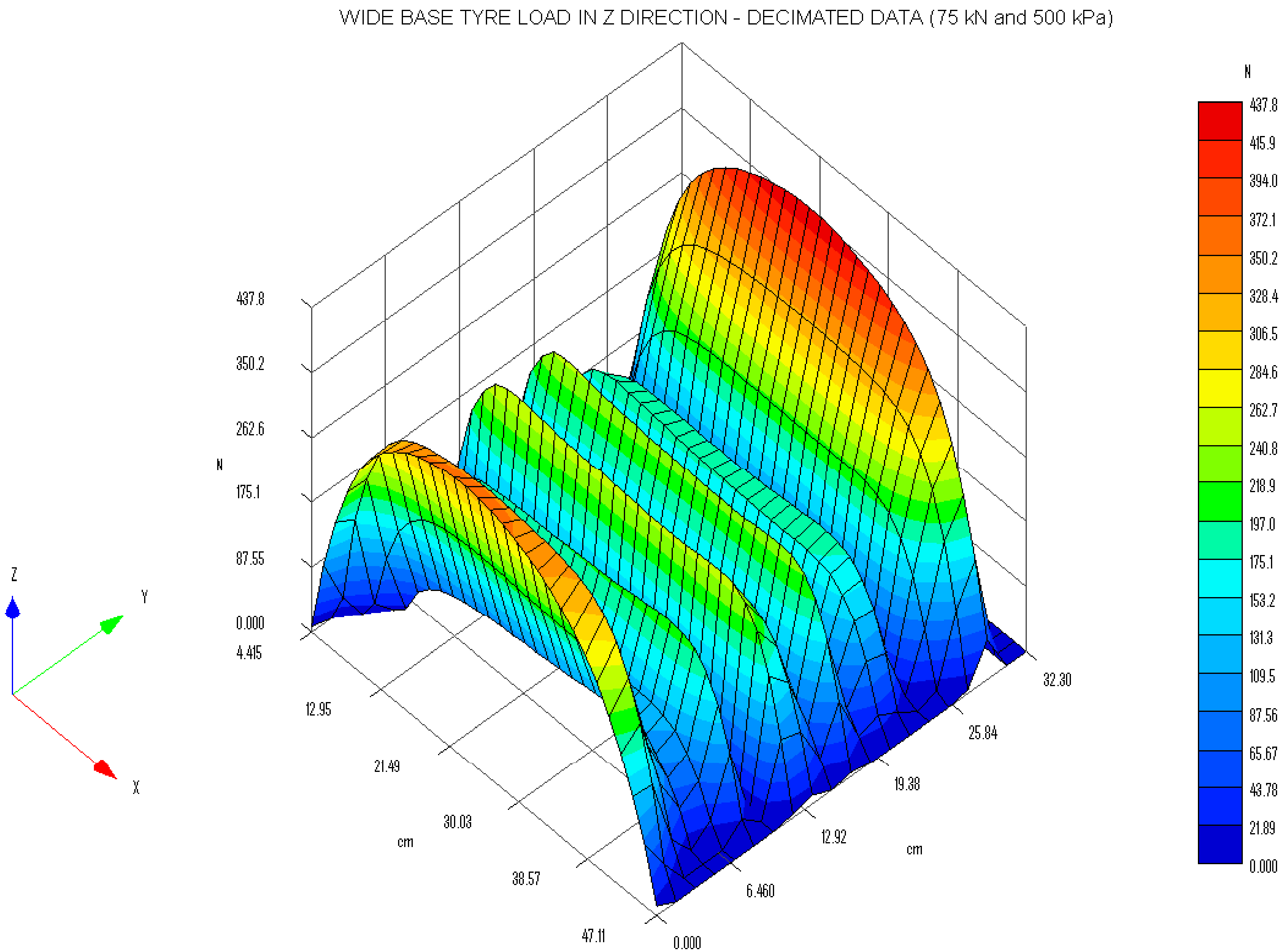
Contact pressure measured by SIM (provided by Prof. Morris De Beer)



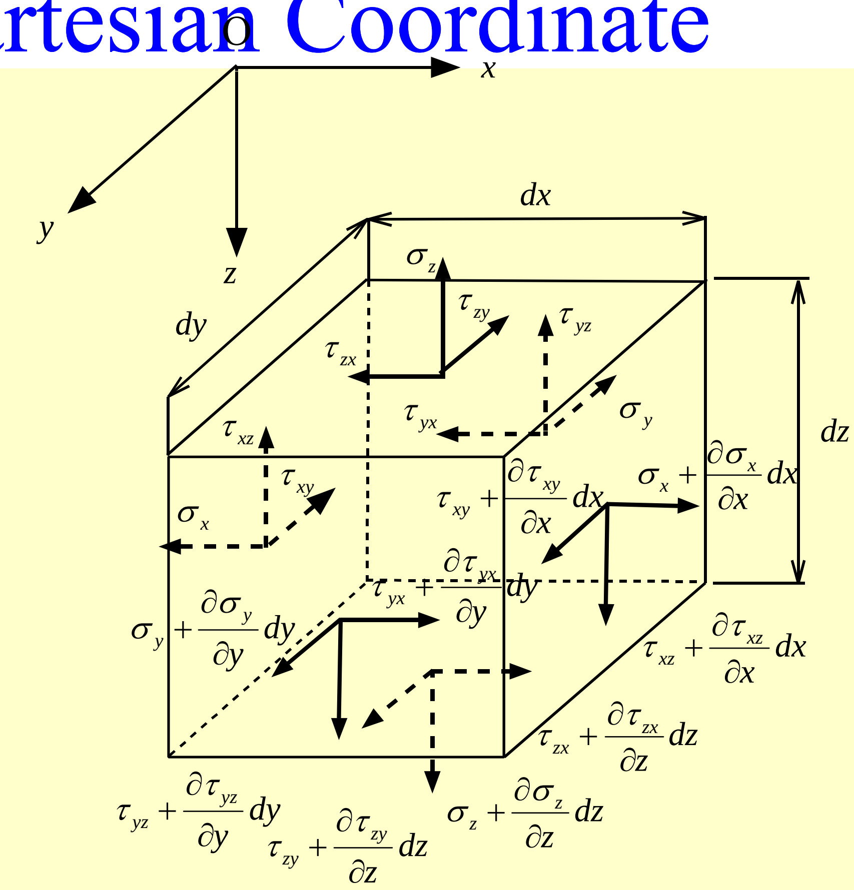
Contact pressure measured by SIM (provided by Prof. Morris De Beer)



Contact pressure measured by SIM (provided by Prof. Morris De Beer)



1. Static Analysis in the Cartesian Coordinate



Equilibrium

$$\frac{\partial \sigma_x}{\partial x} + \frac{\partial \tau_{xy}}{\partial y} + \frac{\partial \tau_{xz}}{\partial z} = 0$$

$$\frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \sigma_y}{\partial y} + \frac{\partial \tau_{zy}}{\partial z} = 0$$

$$\frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \sigma_z}{\partial z} = 0$$

Strain-displacement

$$\varepsilon_x = \frac{\partial u}{\partial x}; \quad \varepsilon_y = \frac{\partial v}{\partial y}; \quad \varepsilon_z = \frac{\partial w}{\partial z}$$

$$\gamma_{xy} = \frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}; \gamma_{yz} = \frac{\partial w}{\partial y} + \frac{\partial v}{\partial z}; \gamma_{zx} = \frac{\partial u}{\partial z} + \frac{\partial w}{\partial x}$$

Strain-stress

$$\varepsilon_x = \frac{1}{E}\left(\sigma_x - \nu\sigma_y - \nu\sigma_z\right); \gamma_{xy} = \frac{2(1+\nu)}{E}\tau_{xy}$$

$$\varepsilon_y = \frac{1}{E}\left(\sigma_y - \nu\sigma_z - \nu\sigma_x\right); \gamma_{yz} = \frac{2(1+\nu)}{E}\tau_{yz}$$

$$\varepsilon_z = \frac{1}{E}\left(\sigma_z - \nu\sigma_x - \nu\sigma_y\right); \gamma_{zx} = \frac{2(1+\nu)}{E}\tau_{zx}$$

Method of Solution

- Neuber-Papkovich Representation

$$u = \frac{1}{2\mu} B_x - \frac{\lambda + \mu}{4\mu(\lambda + 2\mu)} \frac{\partial}{\partial x} \left(xB_x + yB_y + zB_z \right)$$

$$v = \frac{1}{2\mu} B_y - \frac{\lambda + \mu}{4\mu(\lambda + 2\mu)} \frac{\partial}{\partial y} \left(xB_x + yB_y + zB_z \right)$$

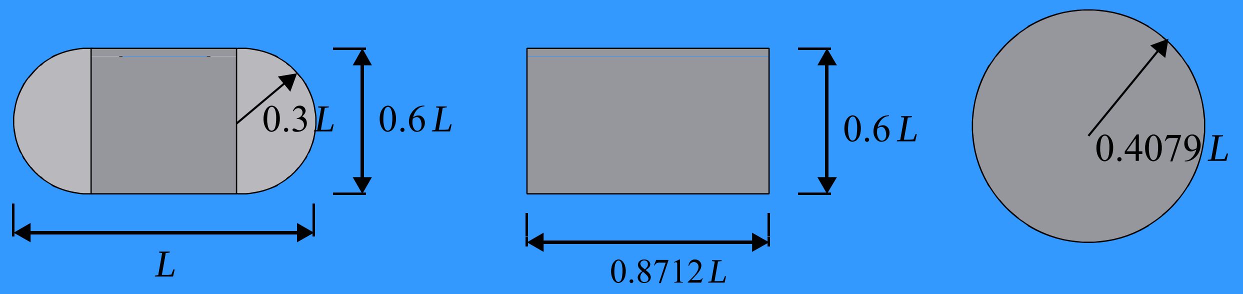
$$w = \frac{1}{2\mu} B_z - \frac{\lambda + \mu}{4\mu(\lambda + 2\mu)} \frac{\partial}{\partial z} \left(xB_x + yB_y + zB_z \right)$$

where

$$\nabla^2 B_x(x,y,z) = \nabla^2 B_y(x,y,z) = \nabla^2 B_z(x,y,z) = 0$$

1. Static Analysis

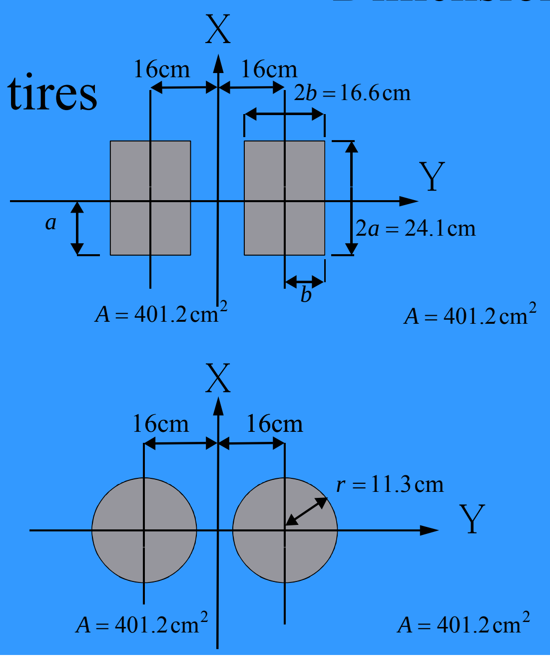
Rectangular Area vs Circular Area



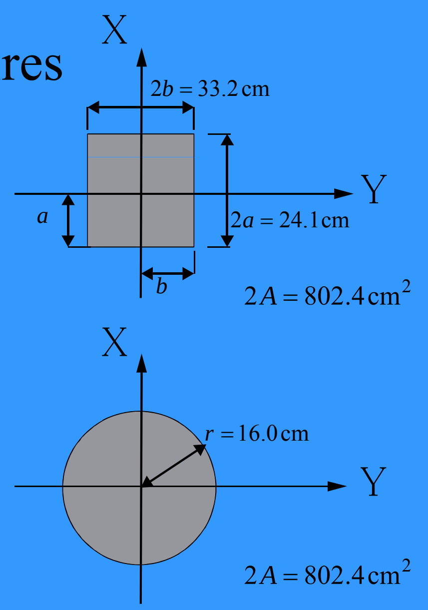
(a) Actual Area (b) Equivalent Area

Dimension of tire contact area

▪Dual tires

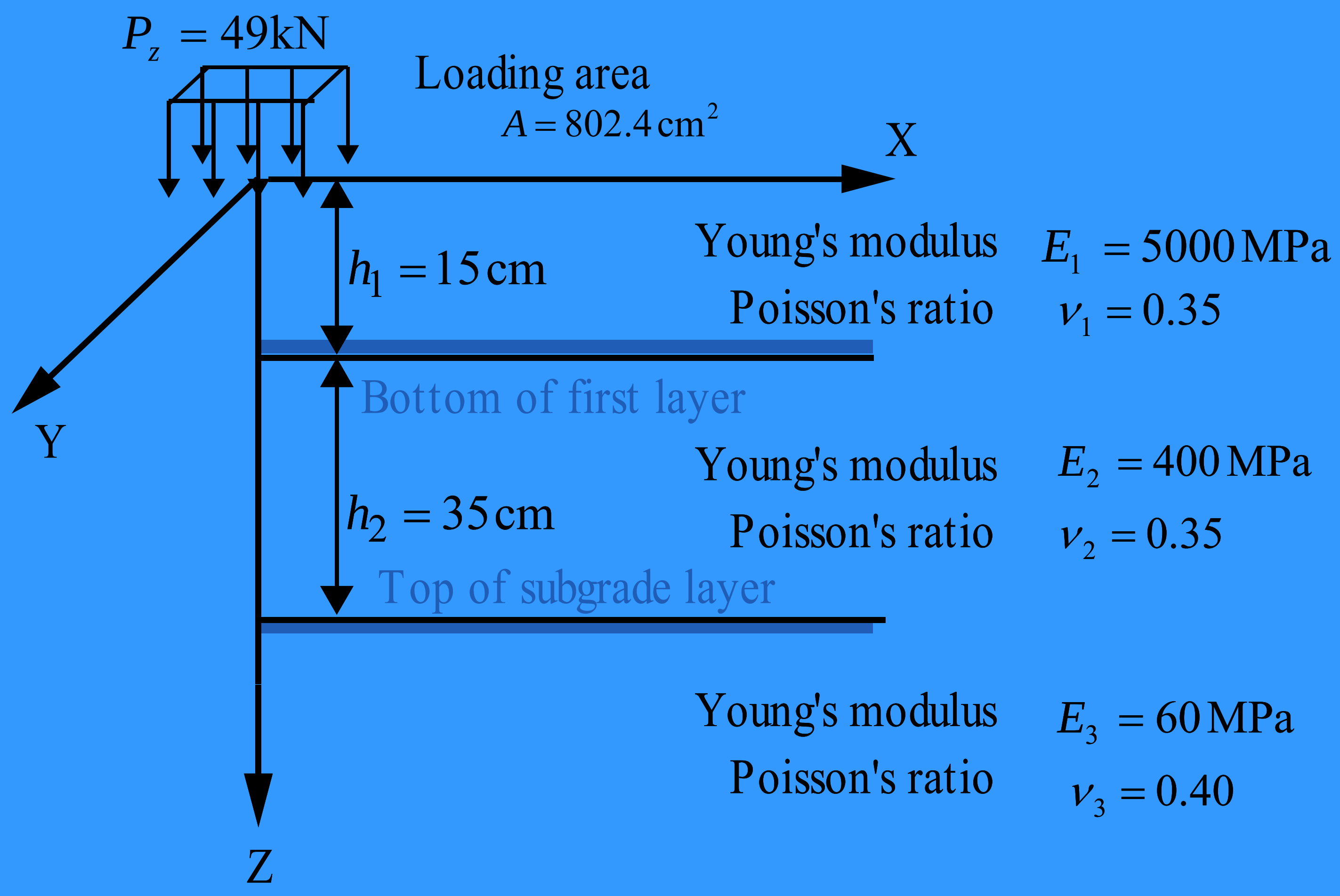


▪Single tires



1. Static Analysis

Rectangular Area vs Circular Area



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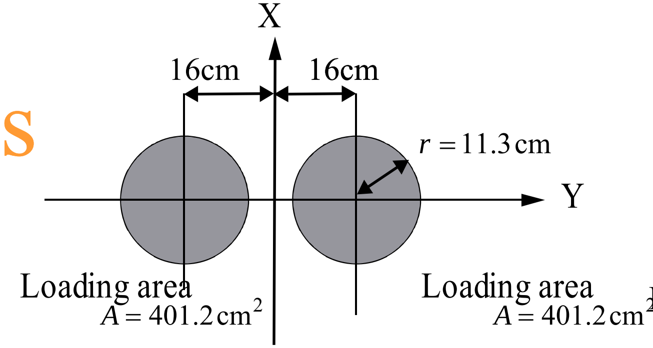
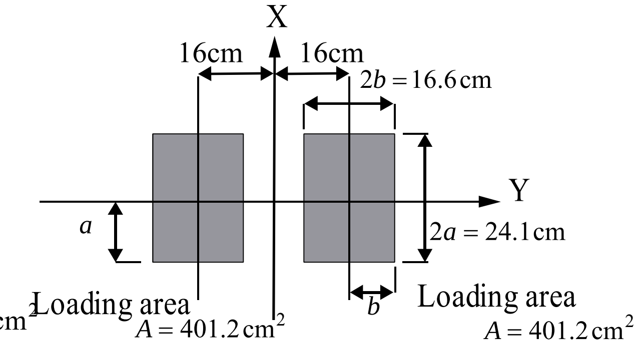
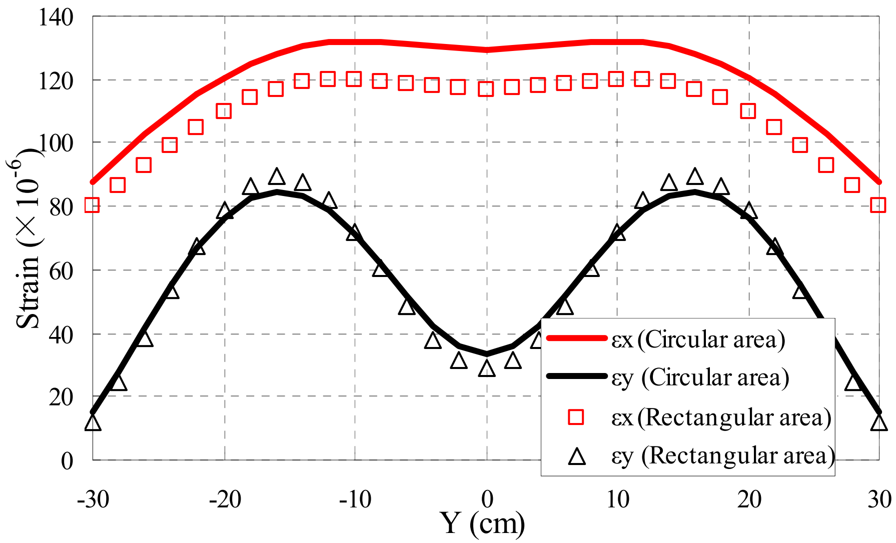
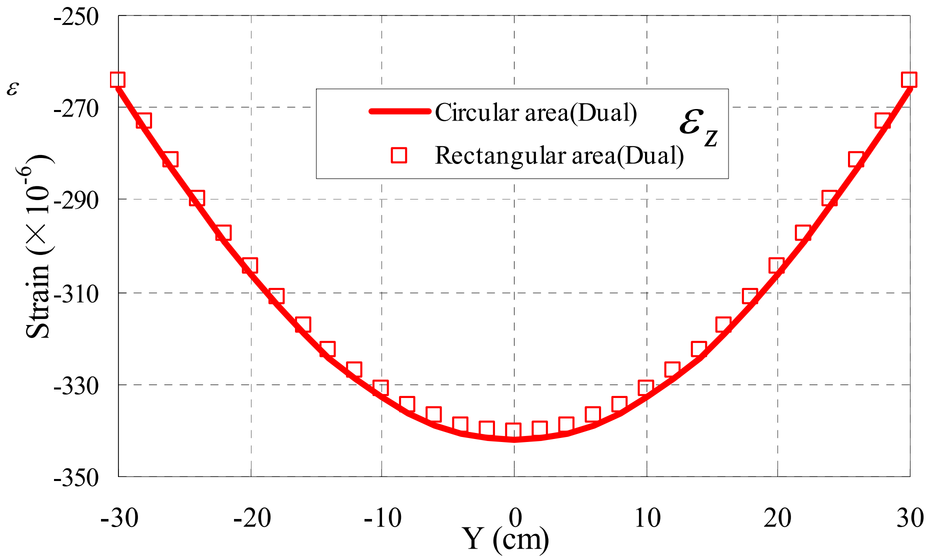




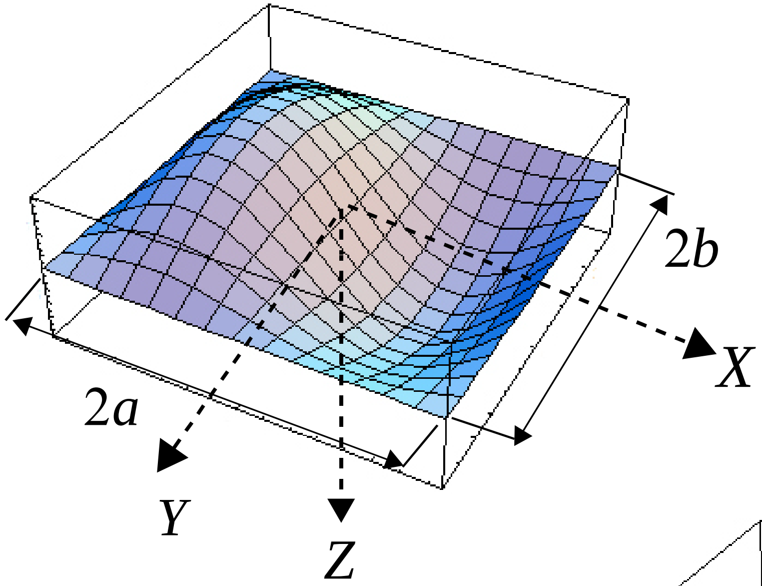
Rectangular Area vs Circular Area

~ Dual tires ~

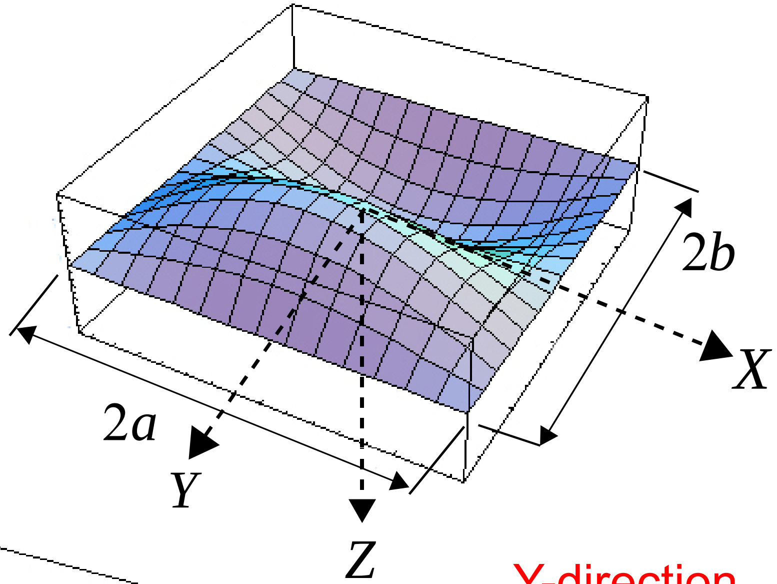




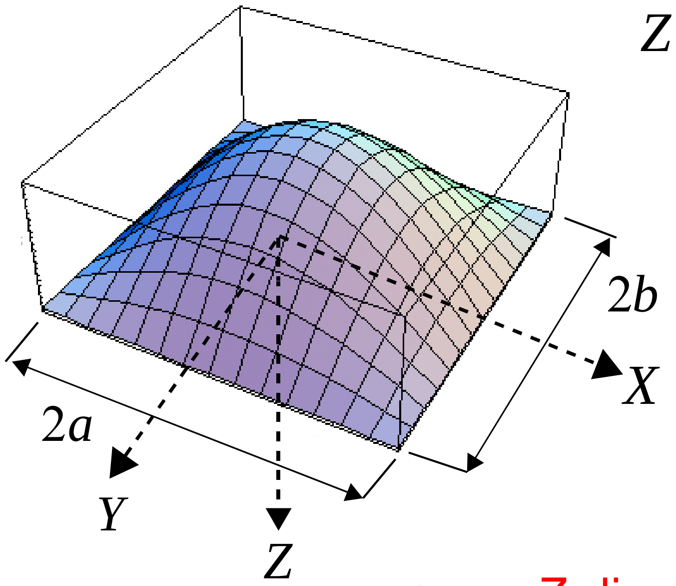
Non-uniform Surface Loading



X-direction

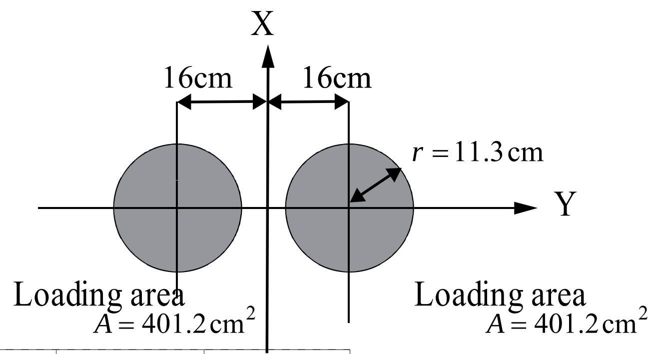


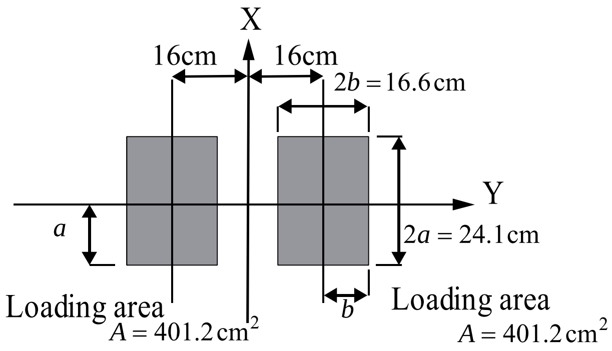
Y-direction

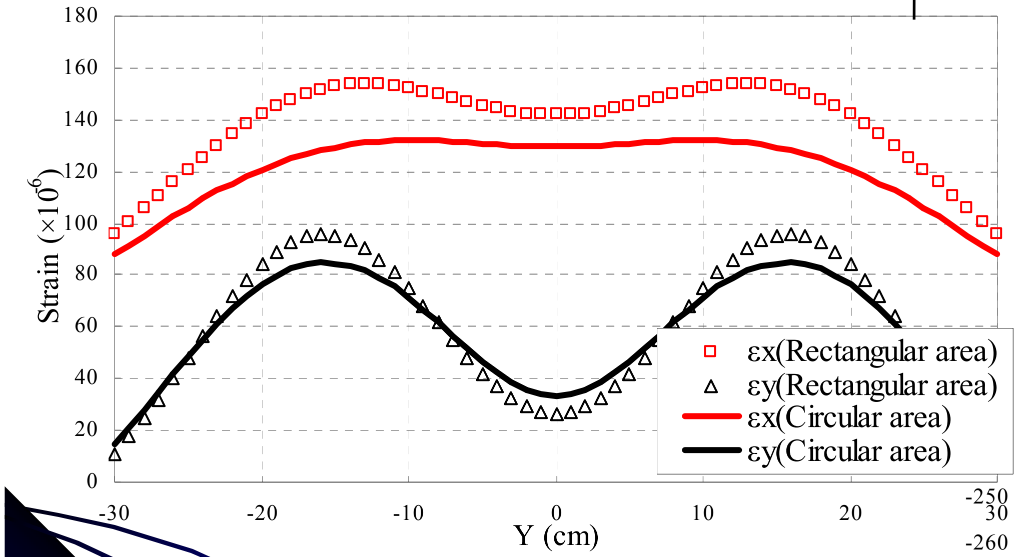


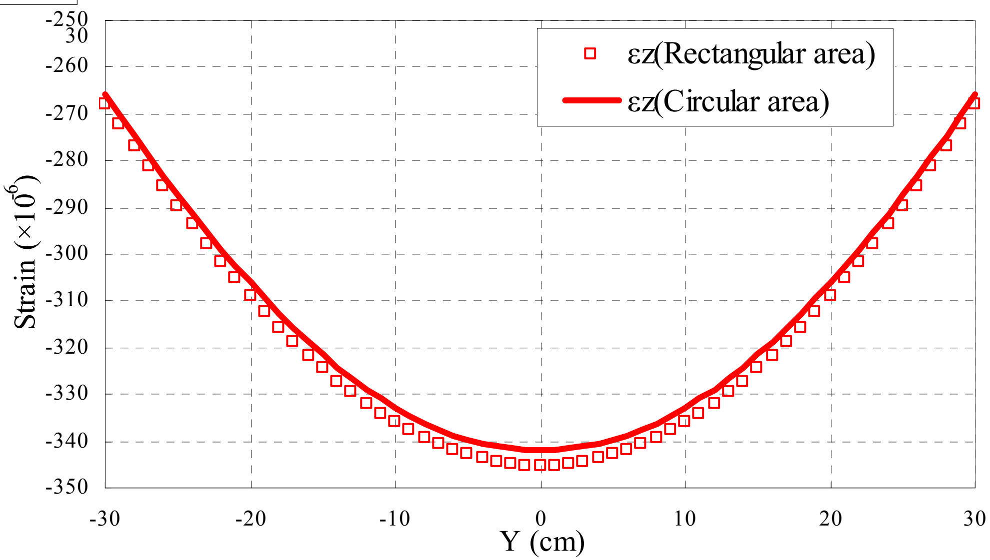
Z-direction

Non-uniform loading









Dynamic Analysis of Pavement Structure

2. Dynamic Analysis

2-1. Axi-symmetric wave propagation analysis

$$\frac{\partial \sigma_r}{\partial r} + \frac{\partial \tau_{rz}}{\partial z} + \frac{\sigma_r - \sigma_\theta}{r} = \frac{\partial^2 u}{\partial t^2}$$

$$\frac{\partial \tau_{rz}}{\partial r} + \frac{\partial \sigma_z}{\partial z} + \frac{\tau_{rz}}{r} = \frac{\partial^2 w}{\partial t^2}$$

Strain-Displacement

$$\varepsilon_r = \frac{\partial u}{\partial r}; \quad \gamma_{r\theta} = \frac{1}{r}\frac{\partial u}{\partial \theta} + \frac{\partial v}{\partial r} - \frac{v}{r}$$

$$\varepsilon_\theta = \frac{u}{r} + \frac{1}{r}\frac{\partial v}{\partial \theta}; \quad \gamma_{\theta z} = \frac{1}{r}\frac{\partial w}{\partial \theta} + \frac{\partial v}{\partial z}$$

$$\varepsilon_z = \frac{\partial w}{\partial z}; \quad \gamma_{zr} = \frac{\partial w}{\partial r} + \frac{\partial u}{\partial z}$$

Stress-Strain

$$\begin{Bmatrix} \sigma_r \\ \sigma_\theta \\ \sigma_z \\ \tau_{rz} \end{Bmatrix} = E \begin{pmatrix} a+2b & a & a & 0 \\ a & a+2b & a & 0 \\ a & a & a+2b & 0 \\ 0 & 0 & 0 & b \end{pmatrix} \begin{Bmatrix} \varepsilon_r \\ \varepsilon_\theta \\ \varepsilon_z \\ \gamma_{rz} \end{Bmatrix}$$

$$a = \frac{\nu}{(1+\nu)(1-2\nu)} \qquad b = \frac{1}{2(1+\nu)}$$

FEM formulation

$$[M]\{\ddot{z}\} + [K]\{z\} = \{f\}$$

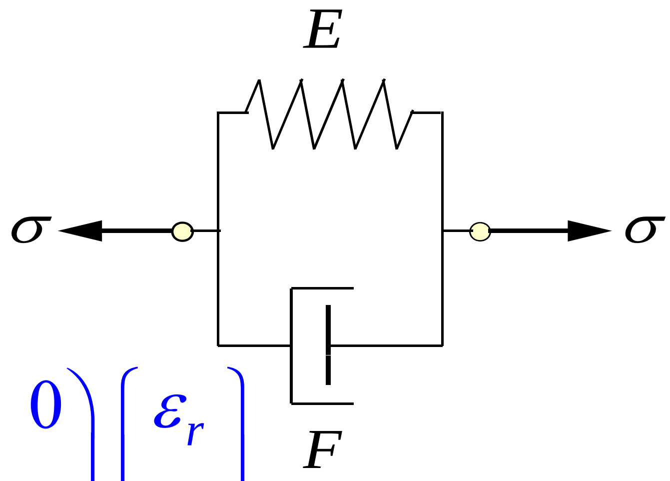
$$\Downarrow$$

$$[M]\{\ddot{z}\} + [C]\{\dot{z}\} + [K]\{z\} = \{f\}$$

$$[C] = \beta[K]$$

2. Dynamic Analysis

- Kelvin Model



$$\begin{Bmatrix}\sigma_r\\ \sigma_\theta\\ \sigma_z\\ \tau_{rz}\end{Bmatrix}=\left(E+F\frac{d}{dt}\right)\begin{pmatrix}a+2b & a & a & 0\\ a & a+2b & a & 0\\ a & a & a+2b & 0\\ 0 & 0 & 0 & b\end{pmatrix}\begin{Bmatrix}\varepsilon_r\\ \varepsilon_\theta\\ \varepsilon_z\\ \gamma_{rz}\end{Bmatrix}$$

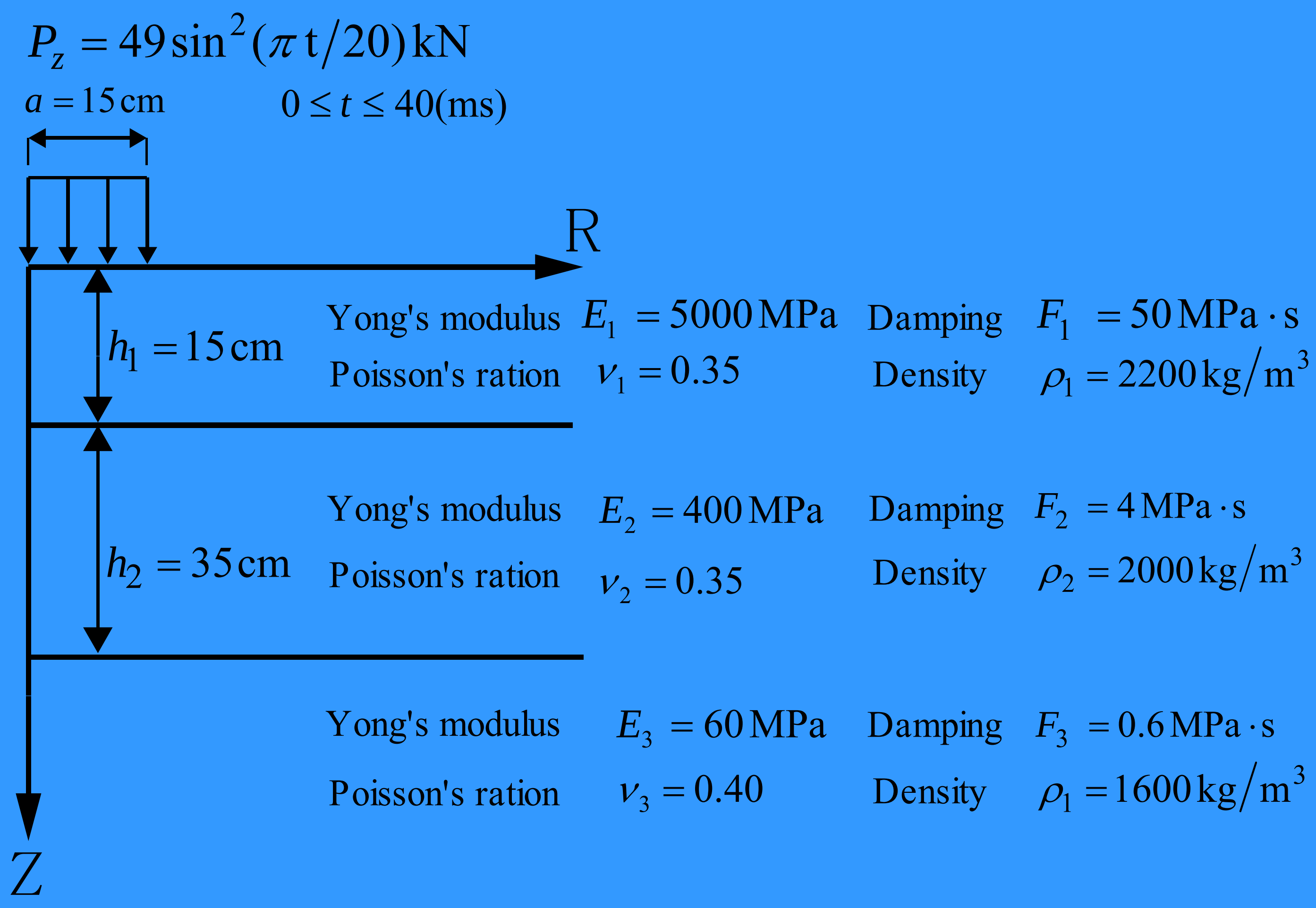
$$a=\frac{\nu}{(1+\nu)(1-2\nu)}\qquad b=\frac{1}{2(1+\nu)}$$

$$[M]\{\ddot{z}\}+[C]\{\dot{z}\}+[K]\{z\}=\{f\}$$

$$[C]=F[B];\quad [K]=E[B]$$

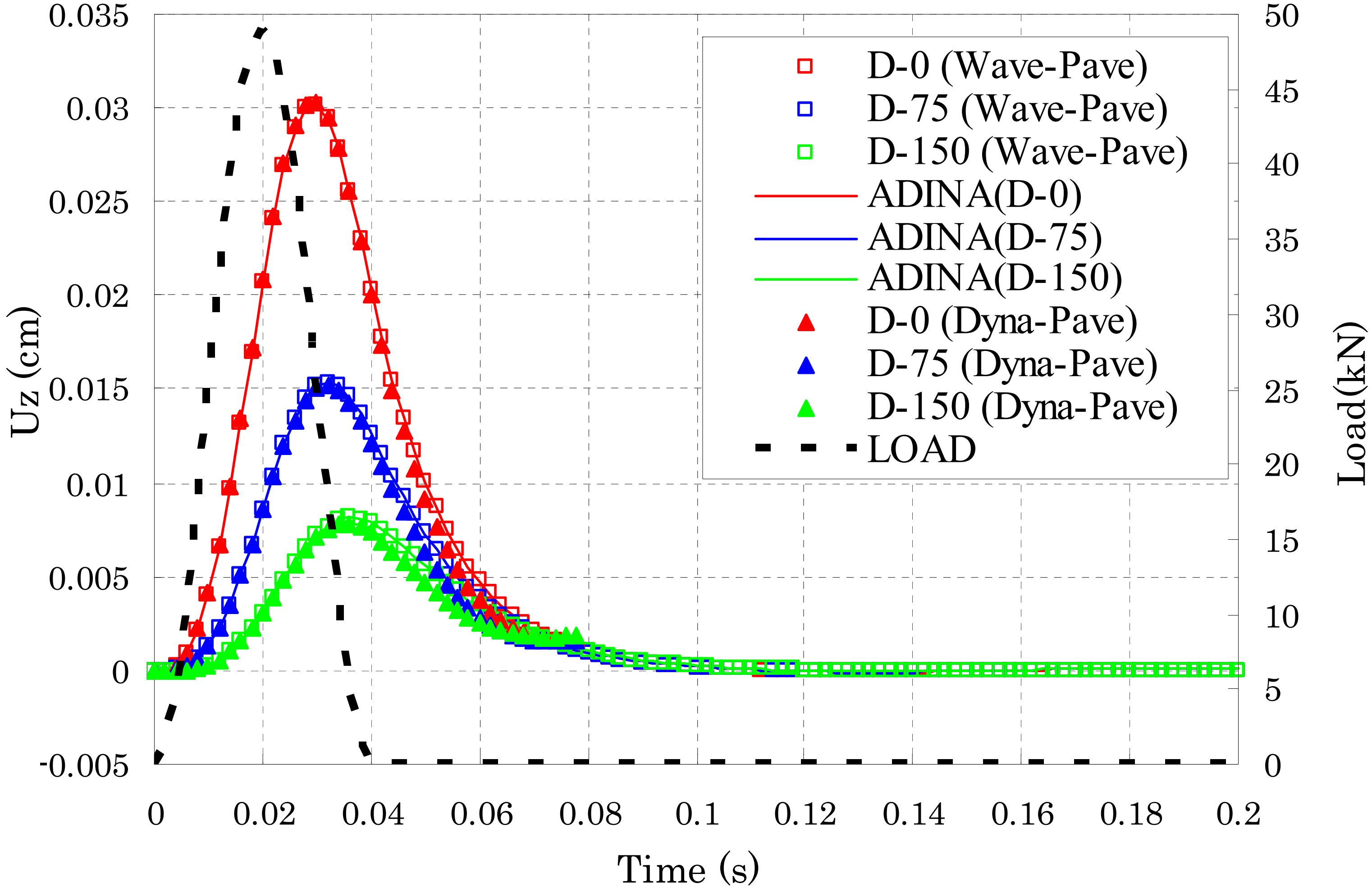
2. Dynamic Analysis

Wave-Pave, Dyna-Pave vs. ADINA



2. Dynamic Analysis

Wave-Pave, Dyna-Pave vs. ADINA

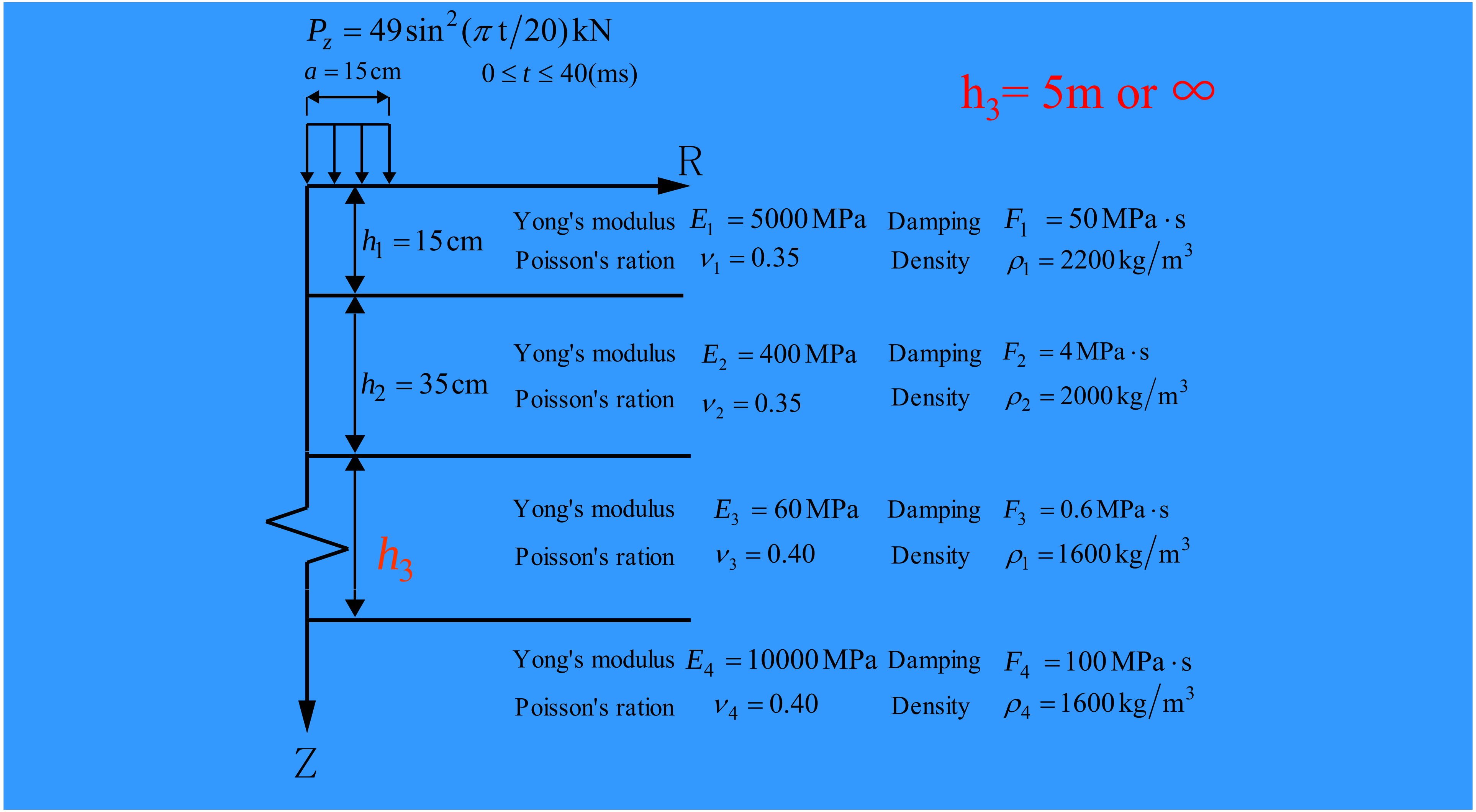


Summary

- Dynamic analysis with stiffness proportional damping is equivalent to dynamic analysis with the Kelvin model

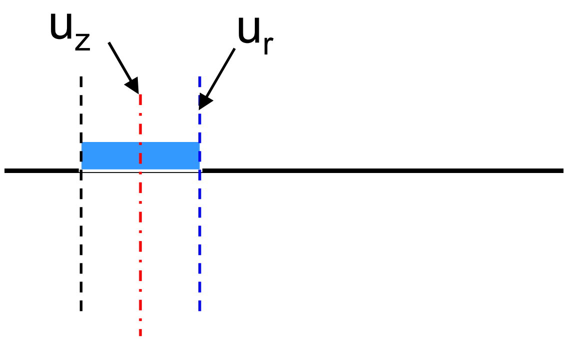
2. Dynamic Analysis

- Wave-Pave

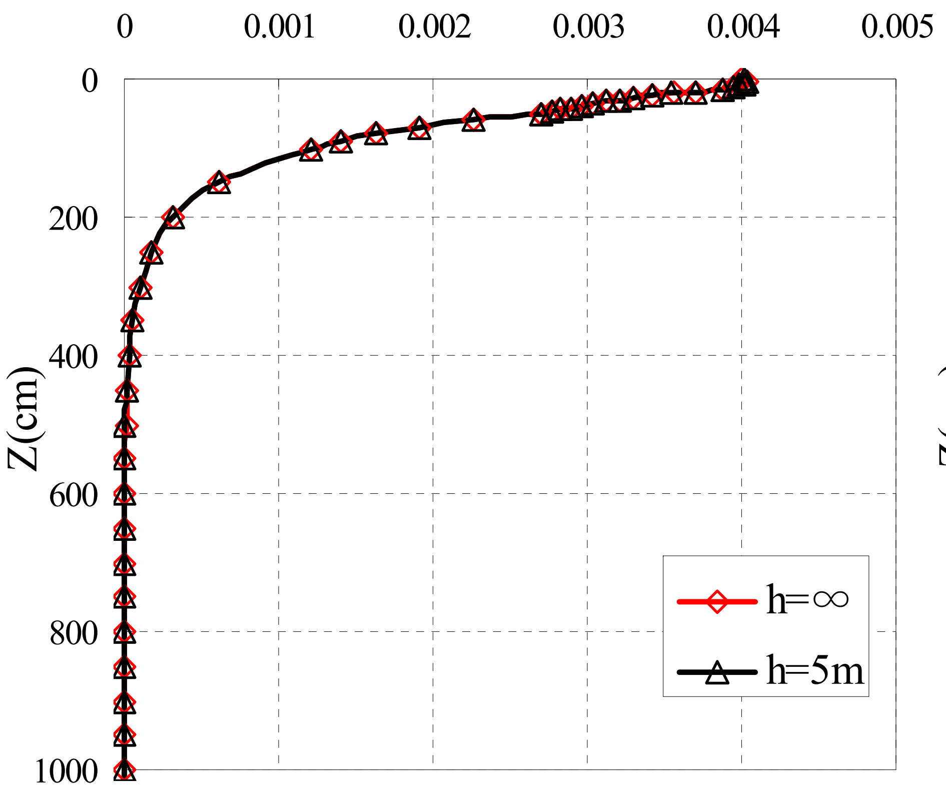


- Wave-Pave

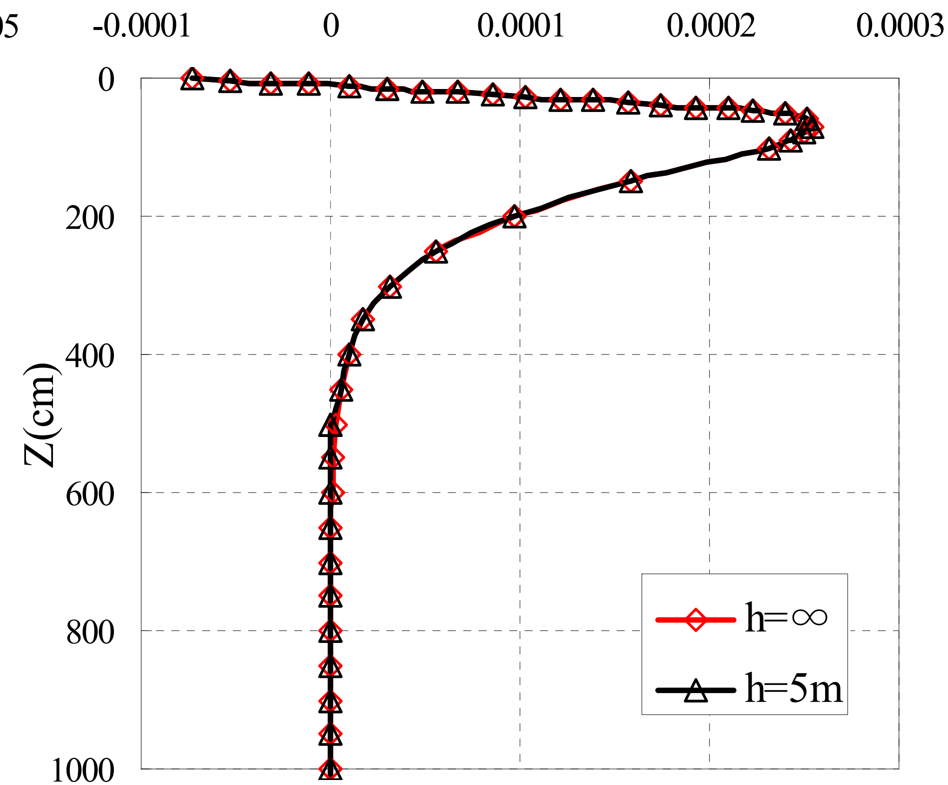
(t=0.01s)



Profile of Vertical displacement, u_z

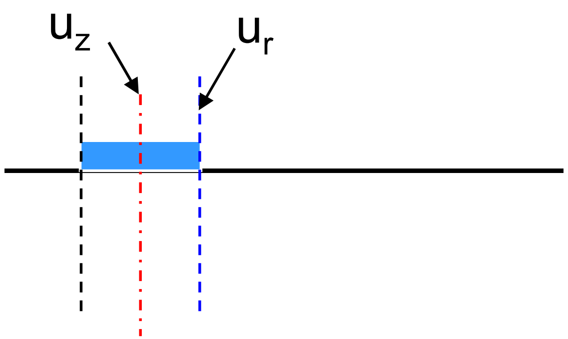


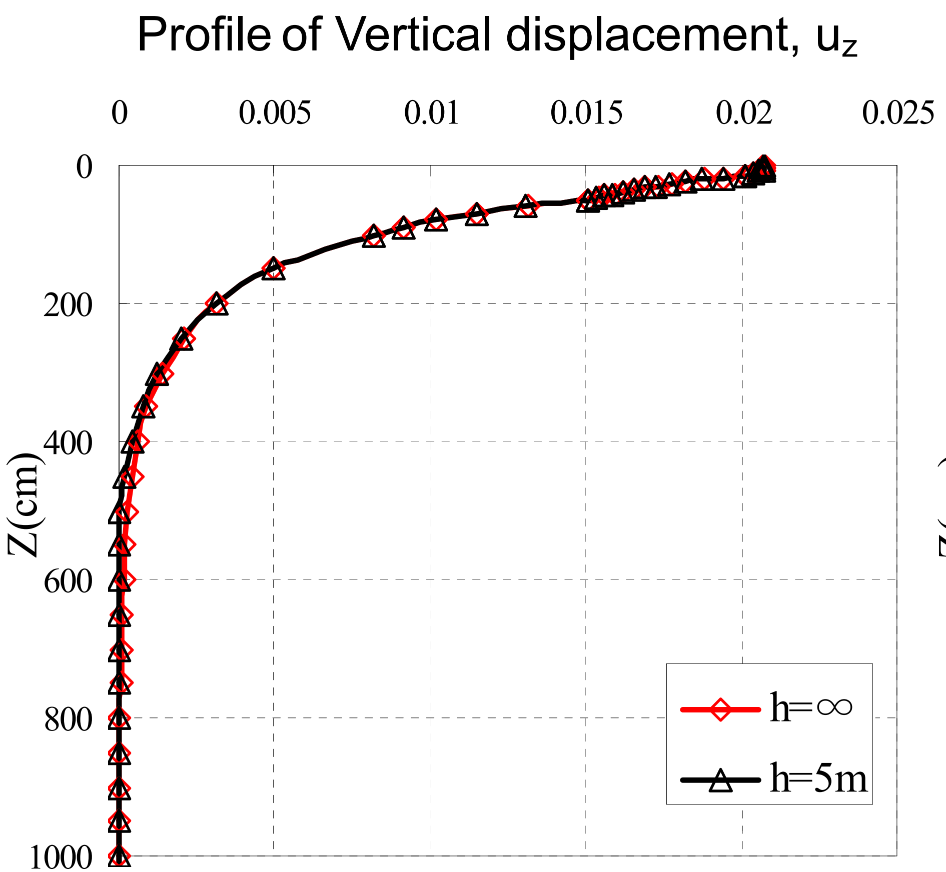
Profile of horizontal displacement, u_r

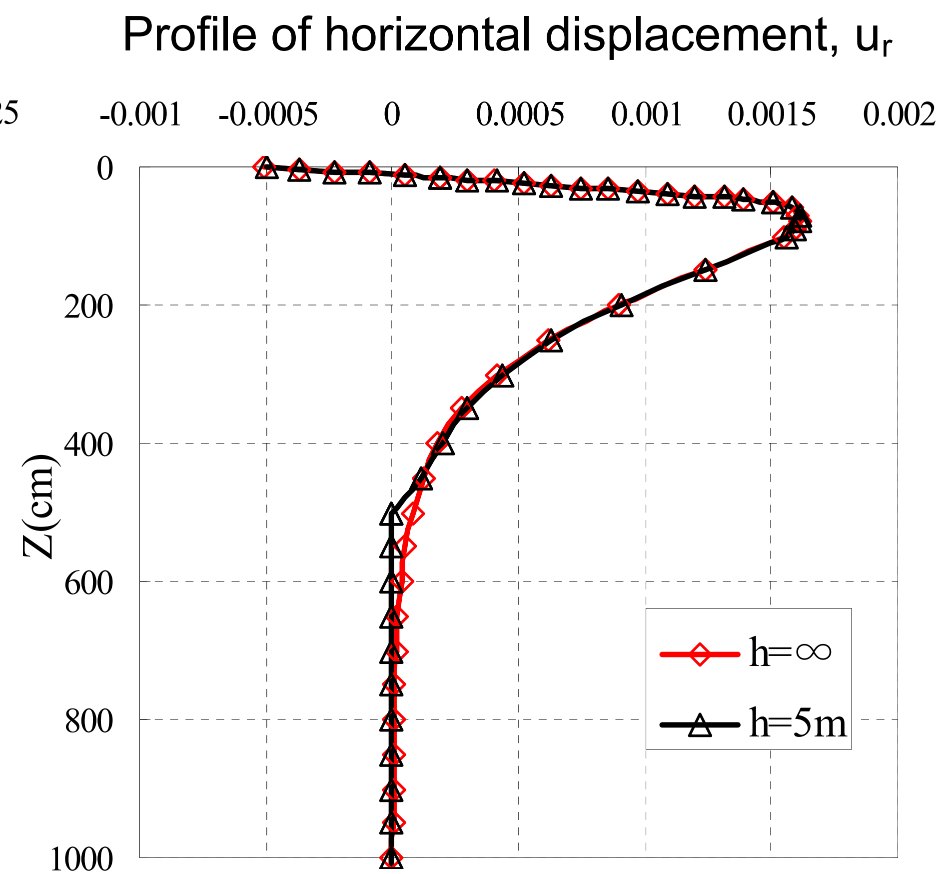


▪ Wave-Pave

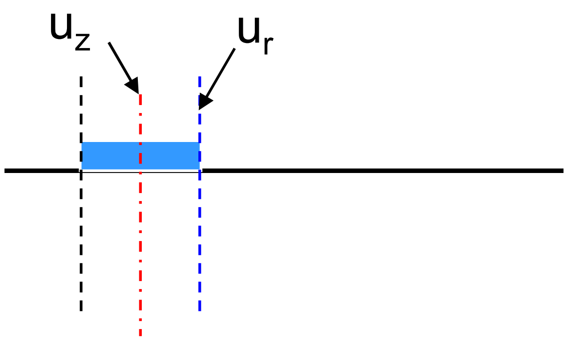
(t=0.02s)



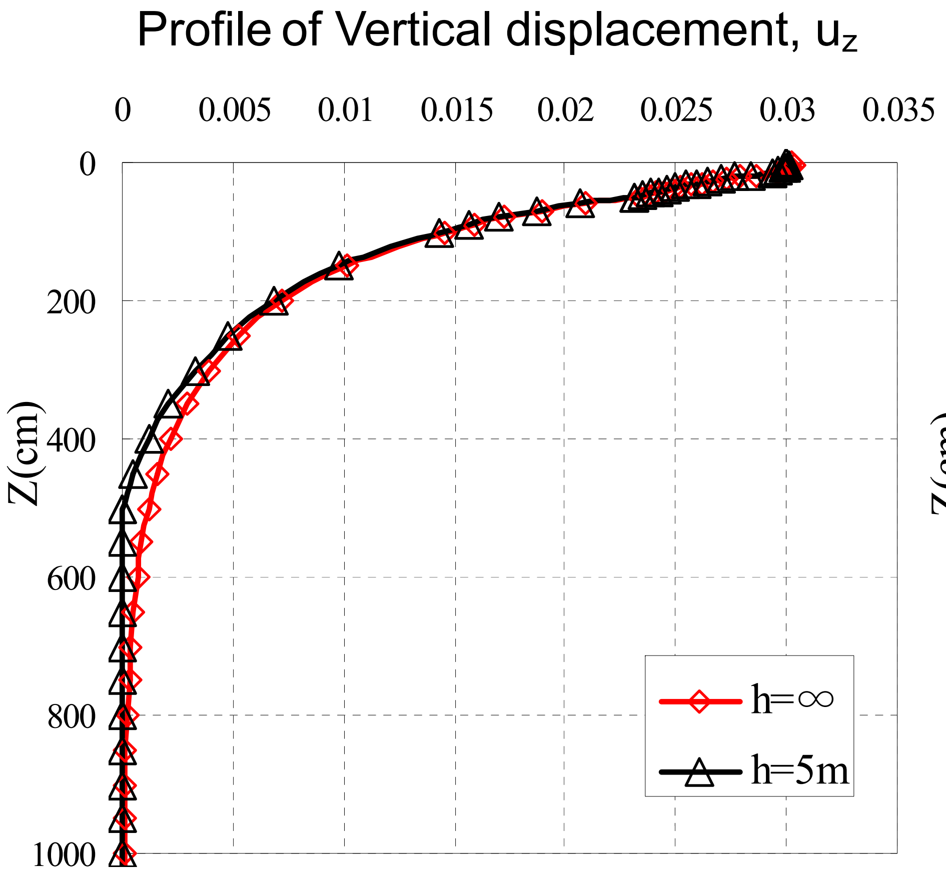


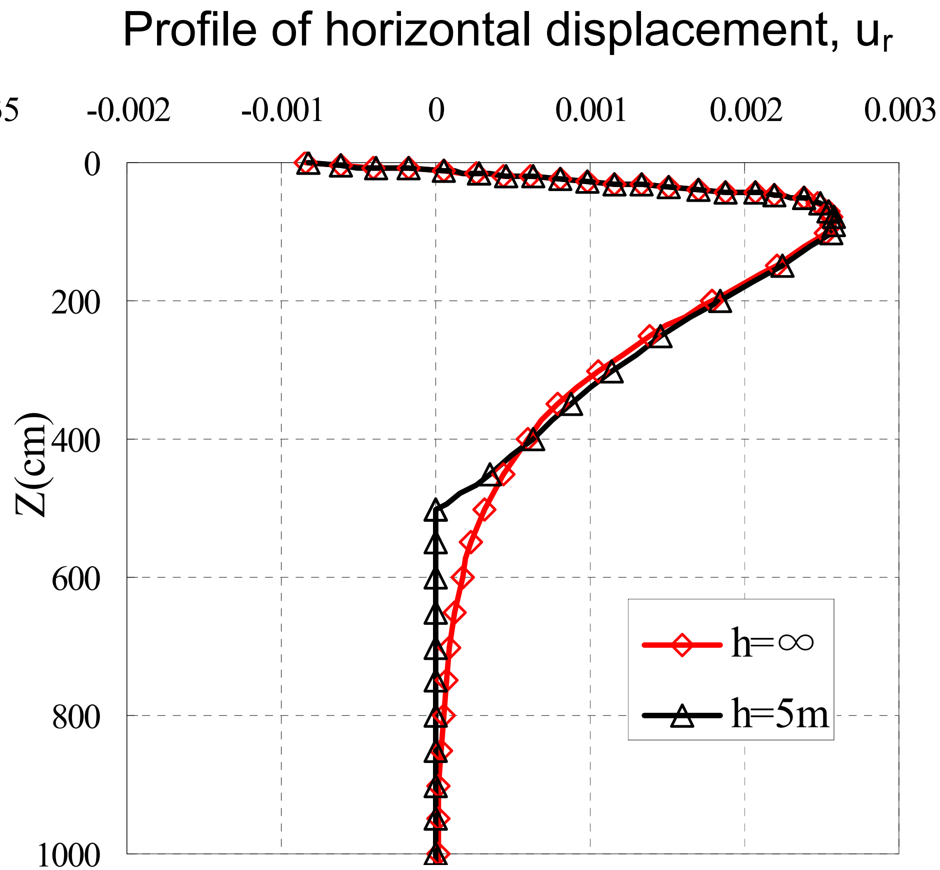


▪ Wave-Pave

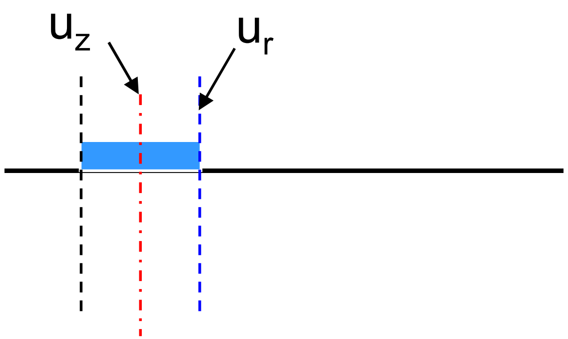


(t=0.03s)



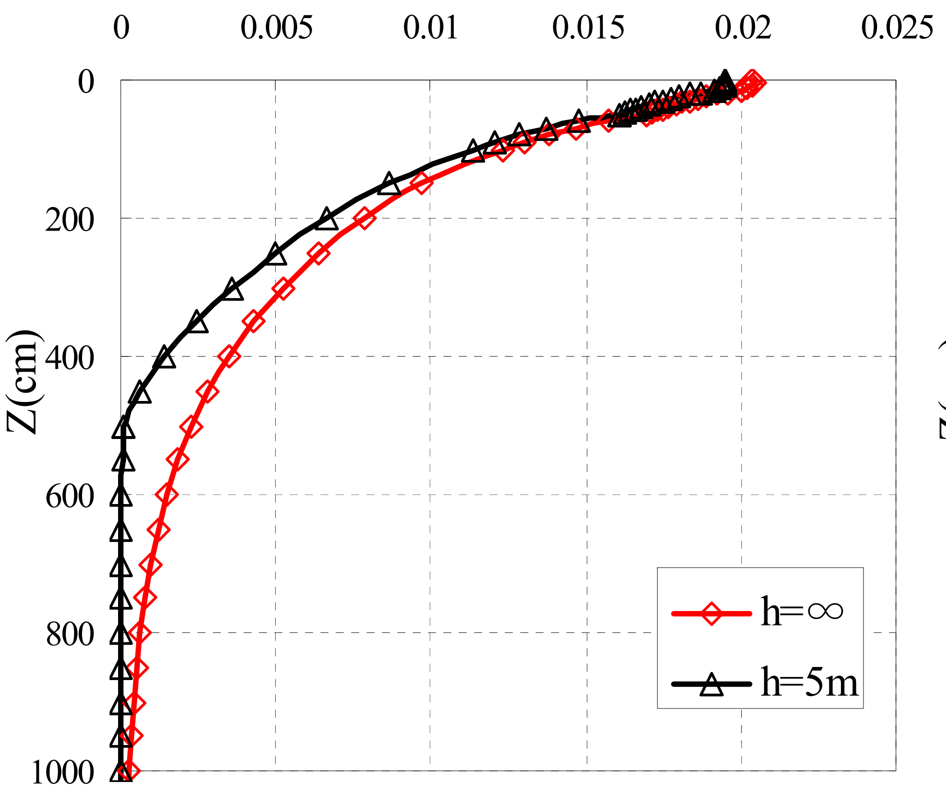


▪ Wave-Pave

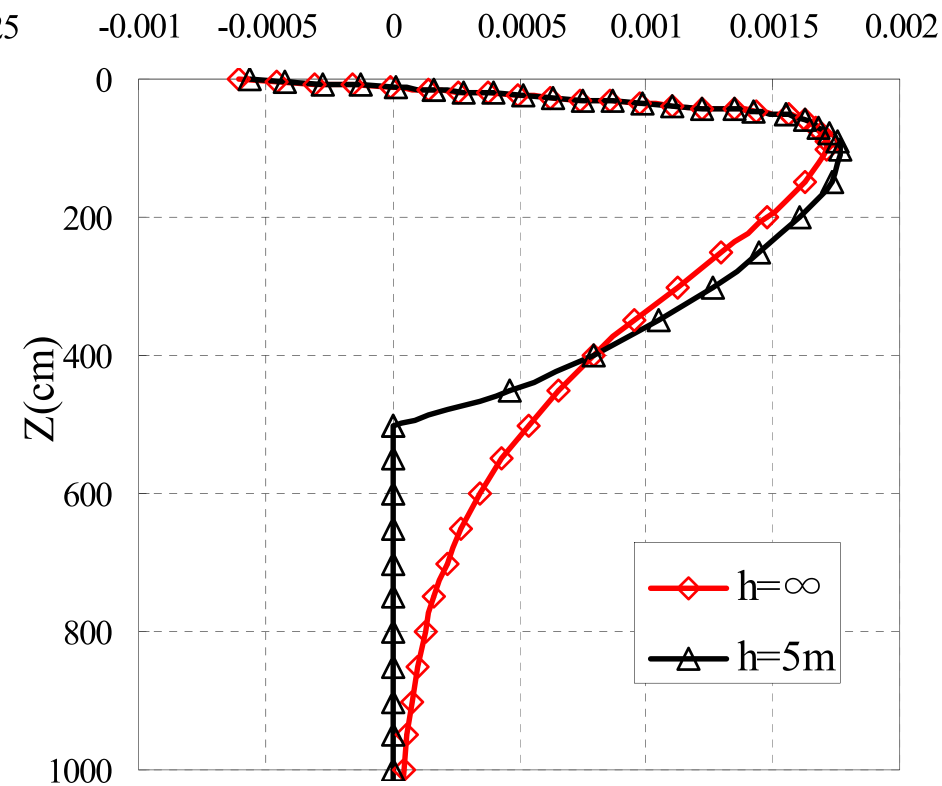


(t=0.04s)

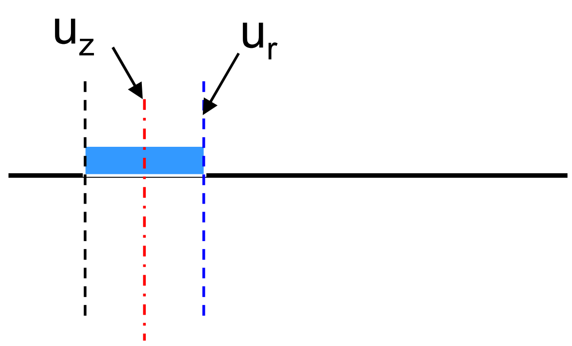
Profile of Vertical displacement, u_z



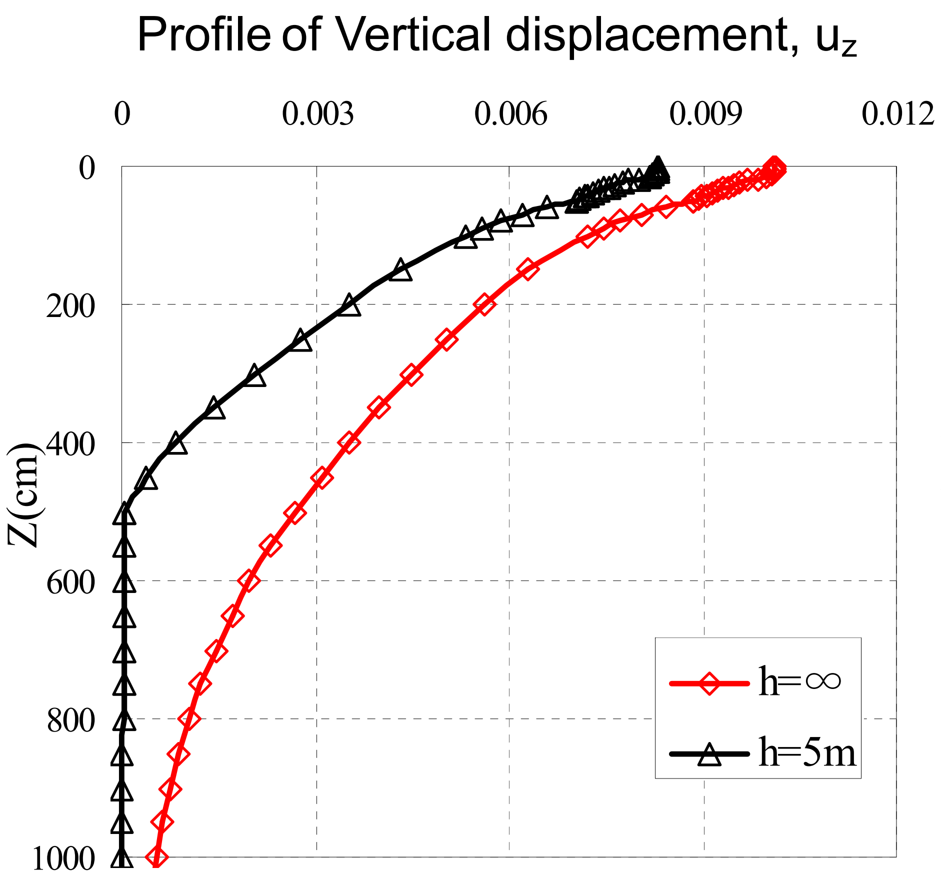
Profile of horizontal displacement, u_r

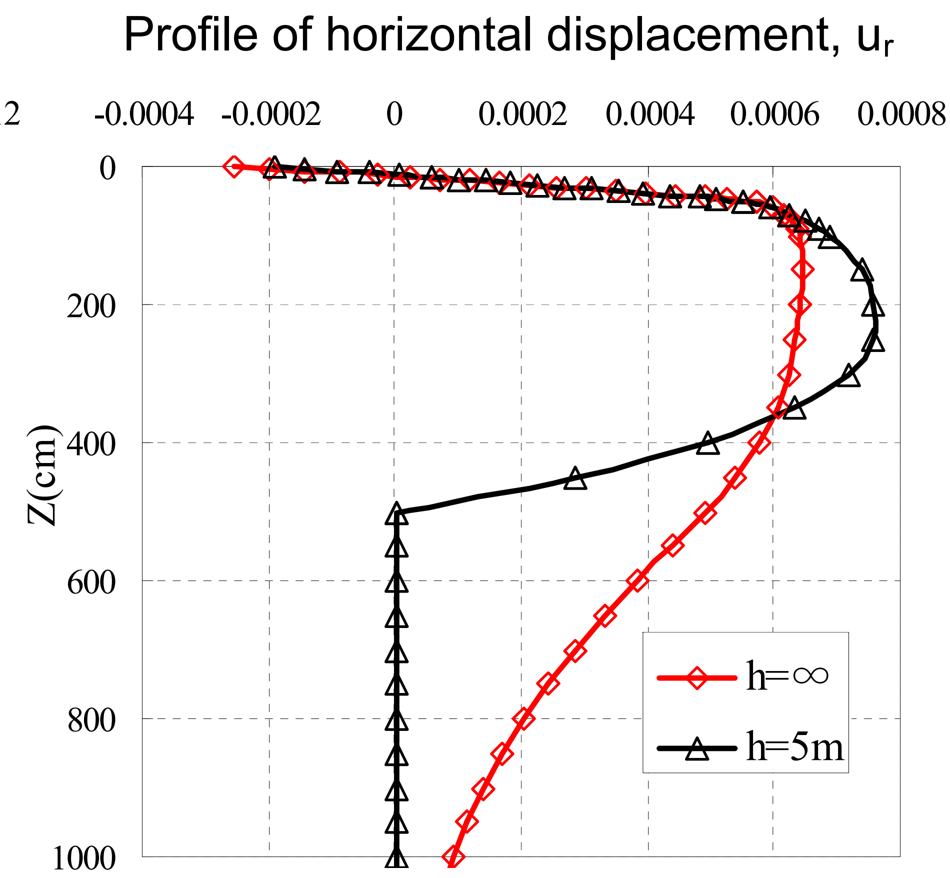


- Wave-Pave

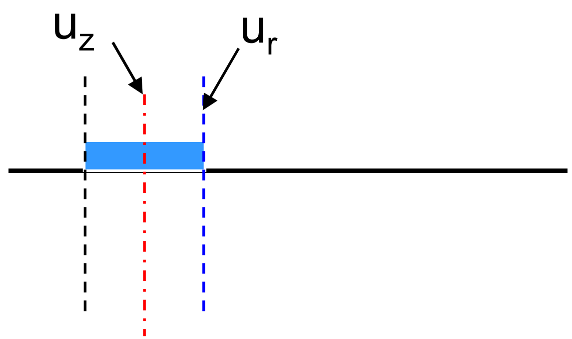


(t=0.05s)



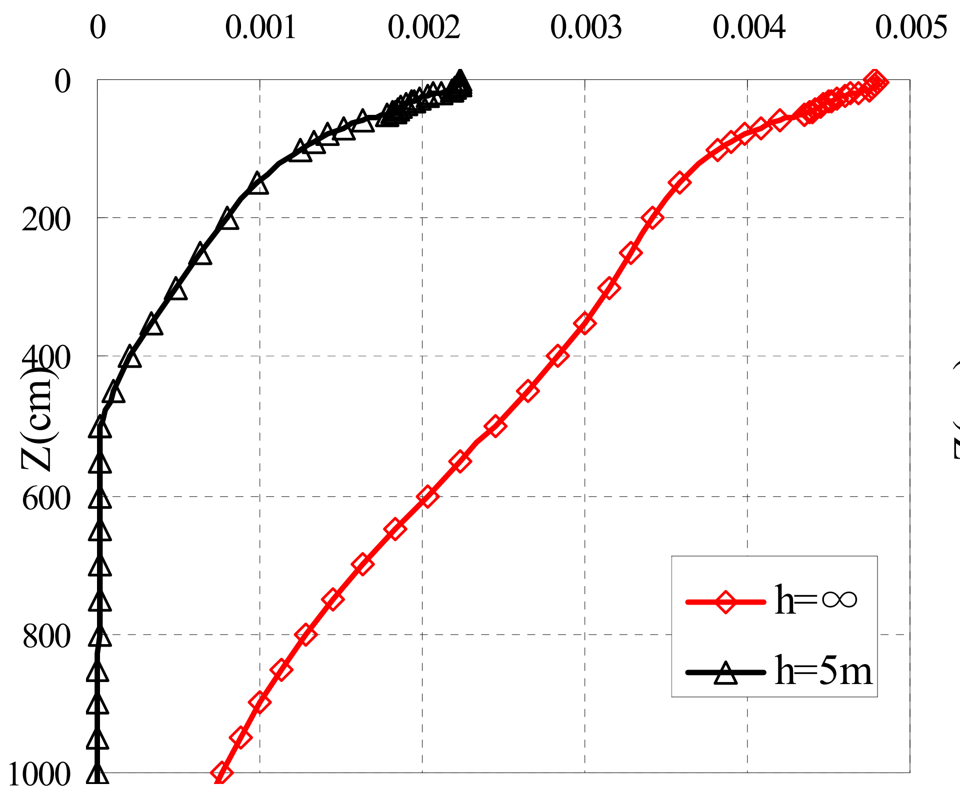


- Wave-Pave

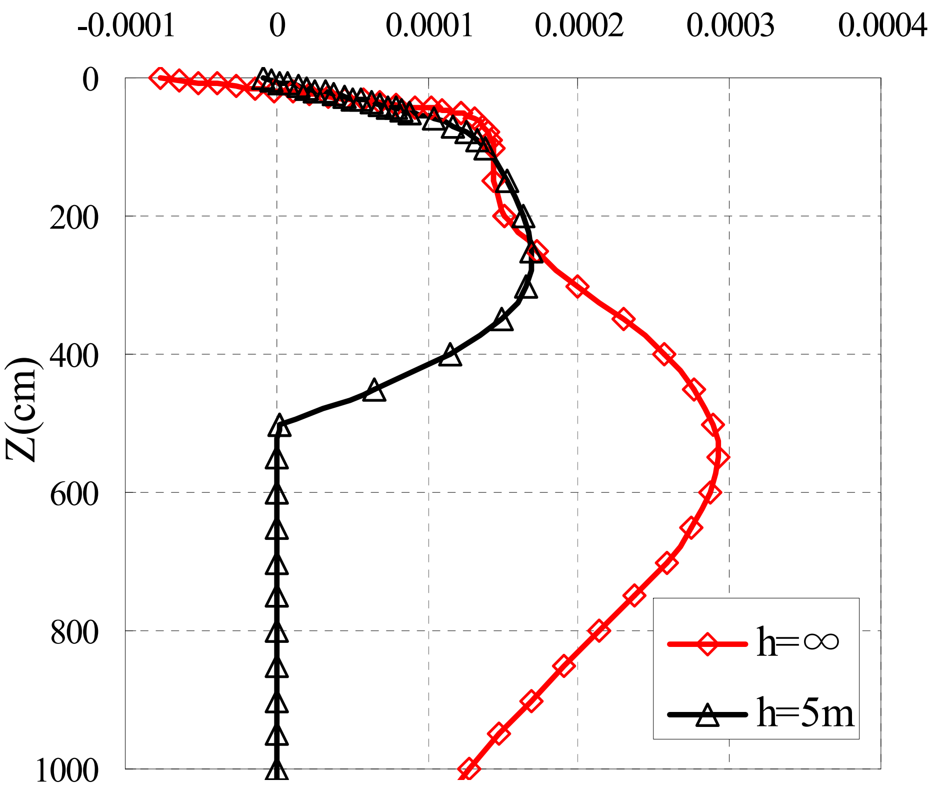


(t=0.06s)

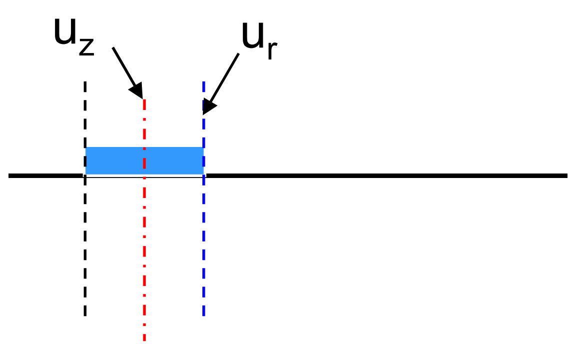
Profile of Vertical displacement, u_z



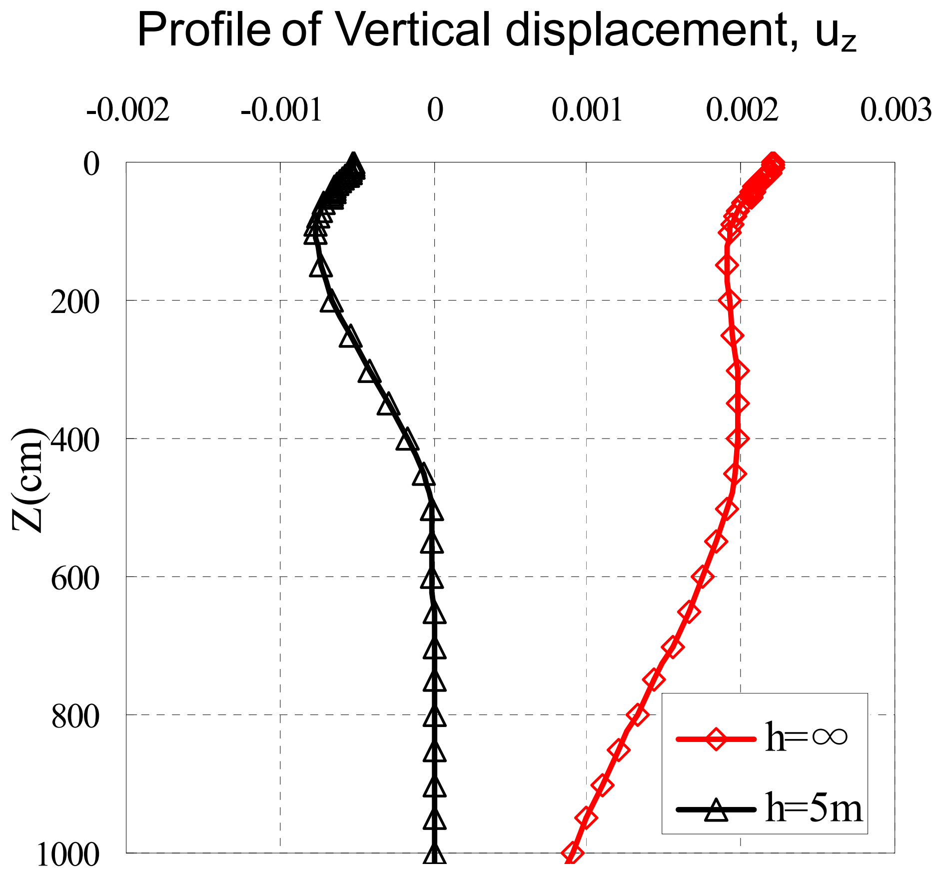
Profile of horizontal displacement, u_r

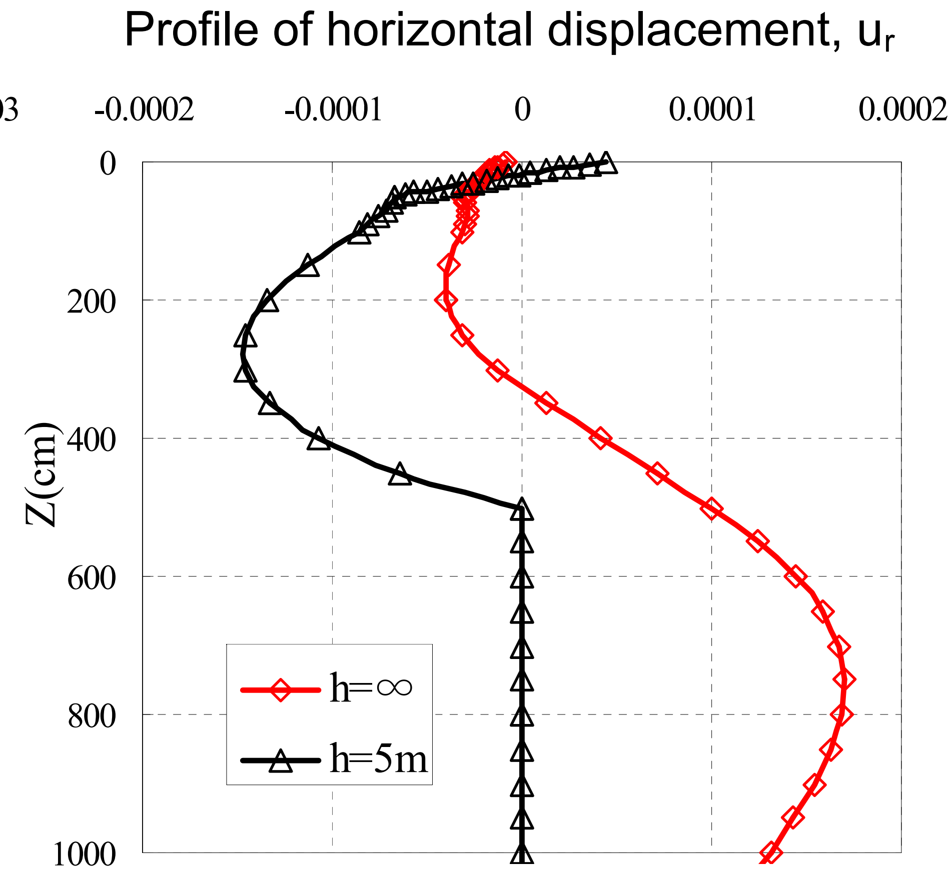


- Wave-Pave

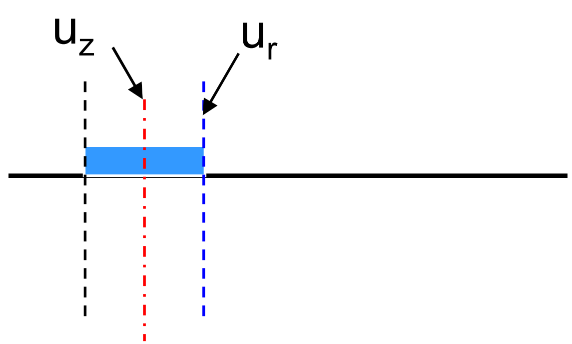


(t=0.07s)



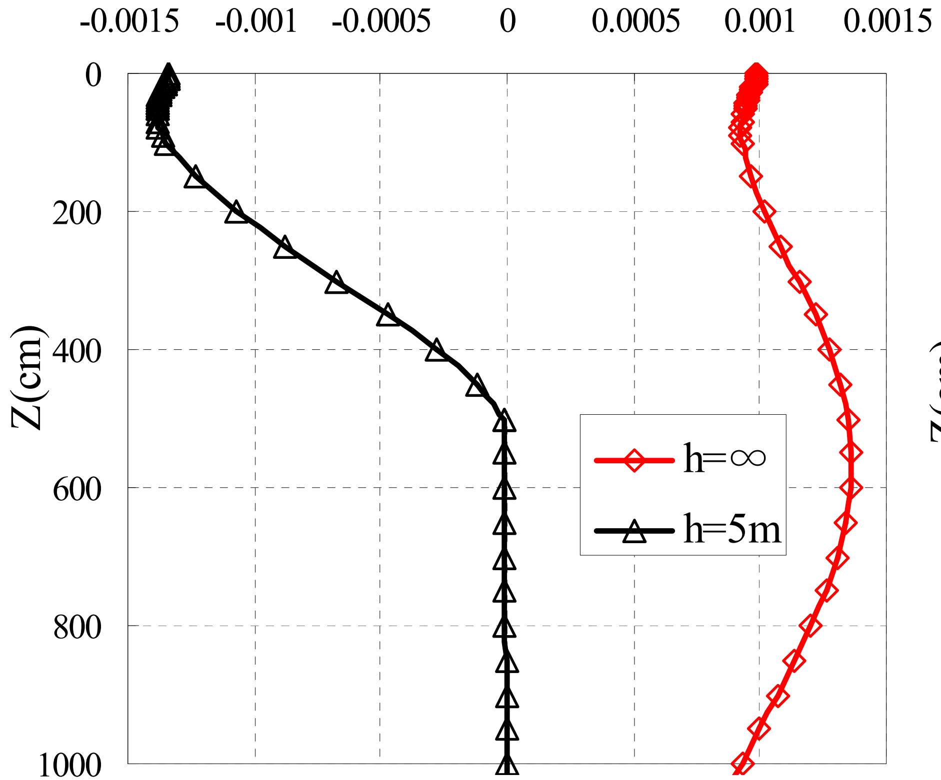


- Wave-Pave

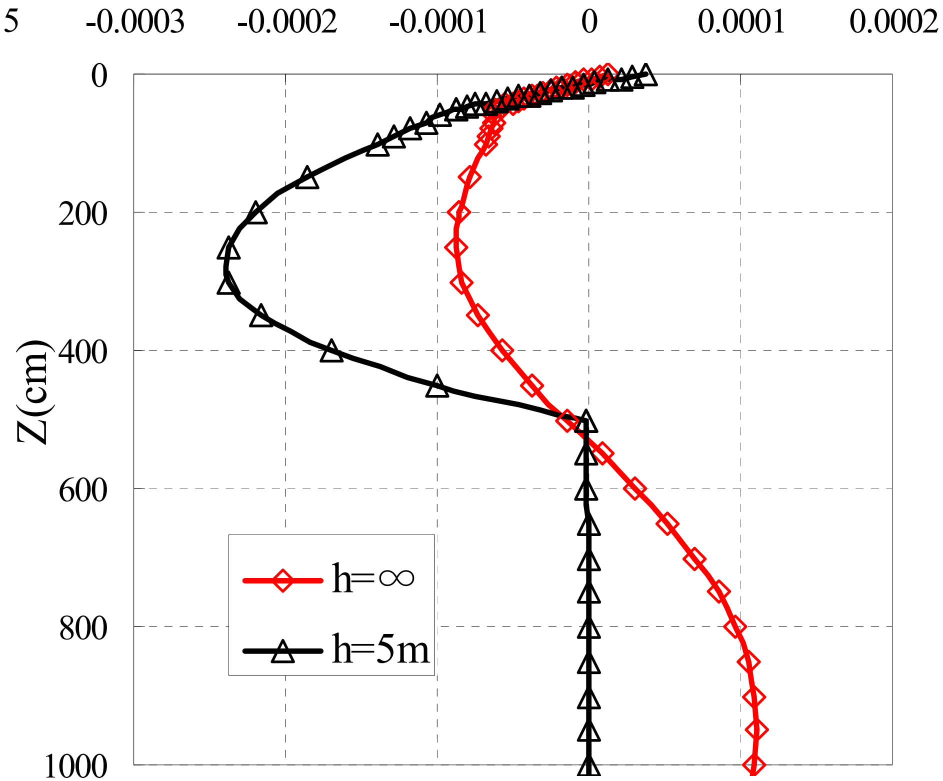


(t=0.08s)

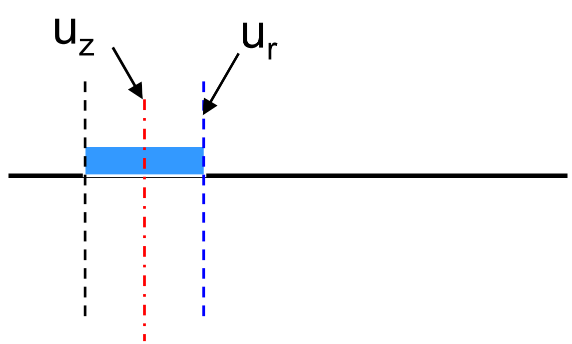
Profile of Vertical displacement, u_z



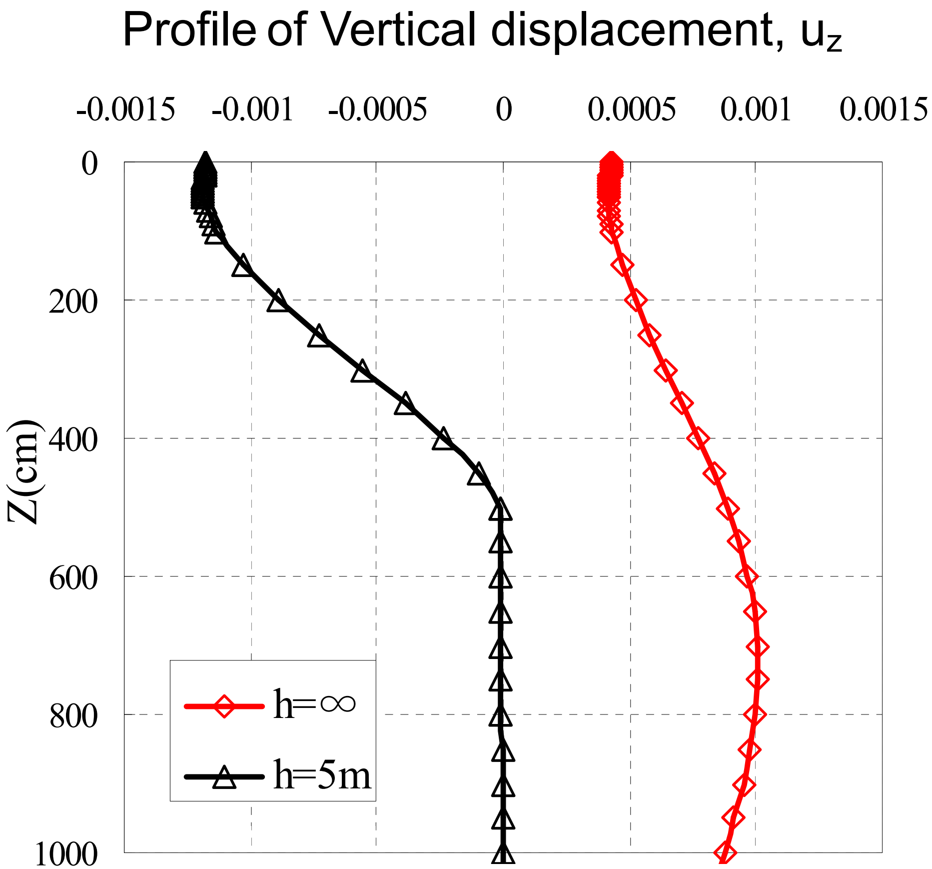
Profile of horizontal displacement, u_r

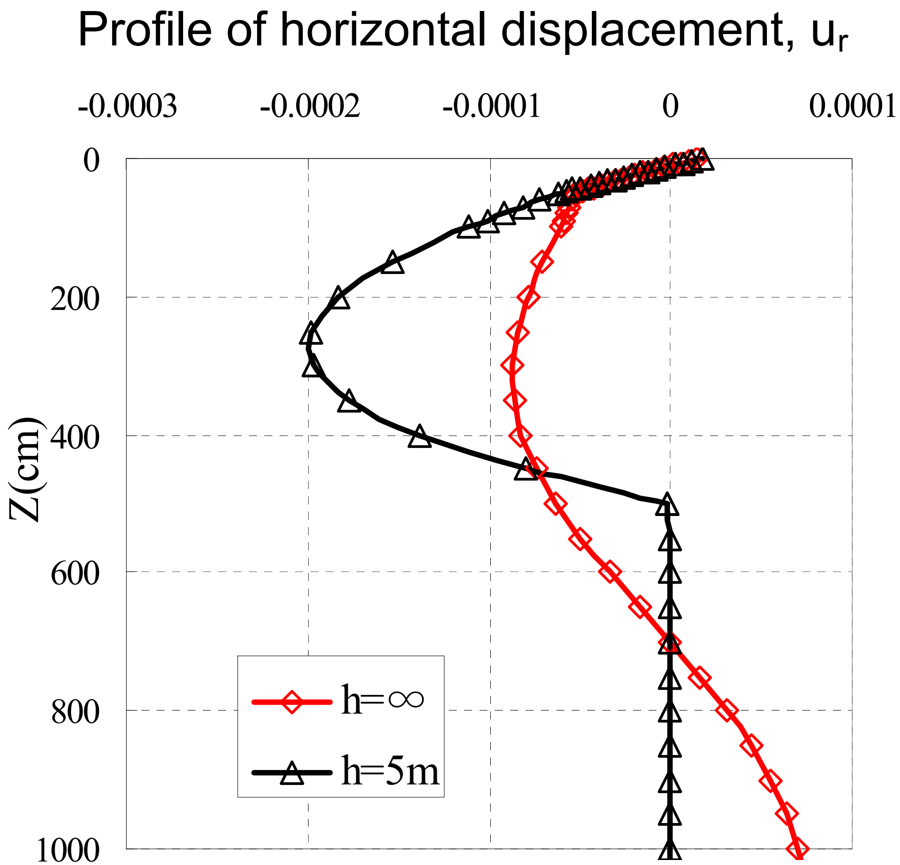


▪ Wave-Pave



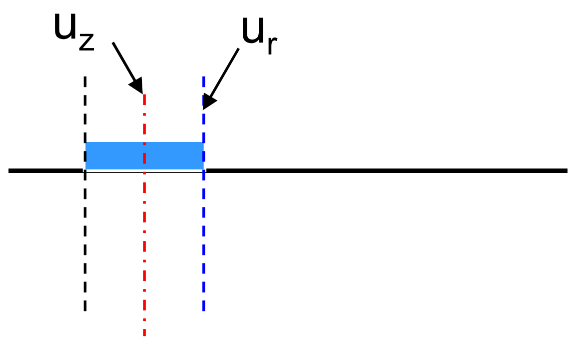
(t=0.09s)

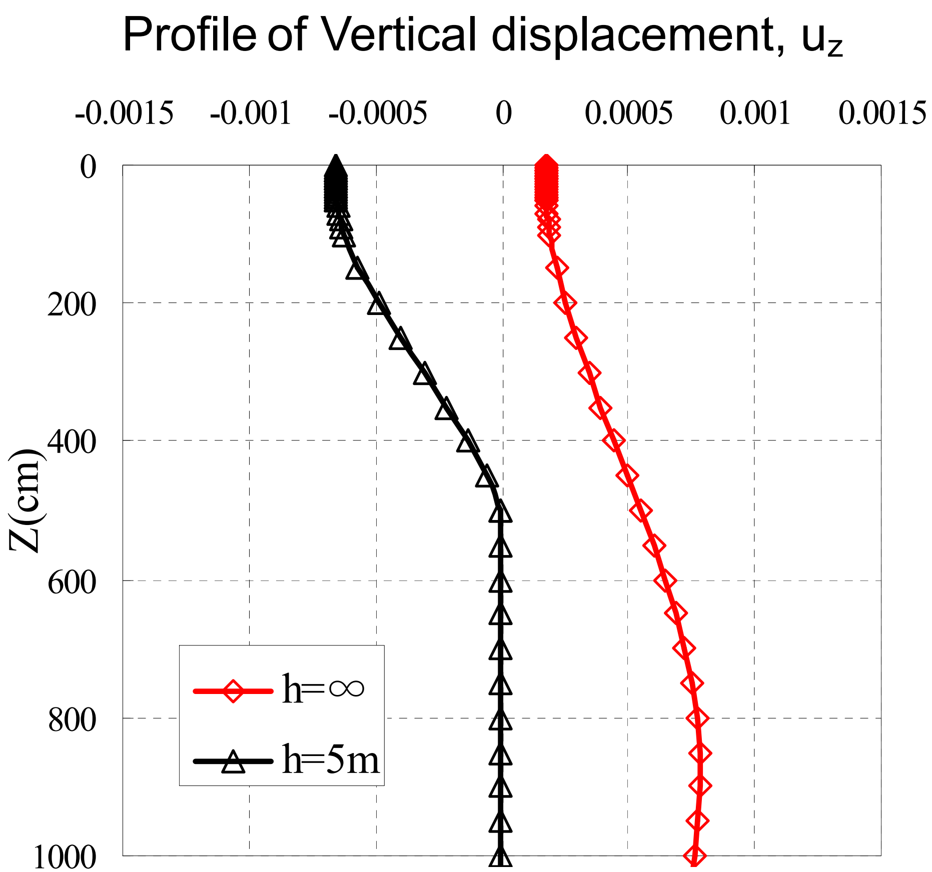


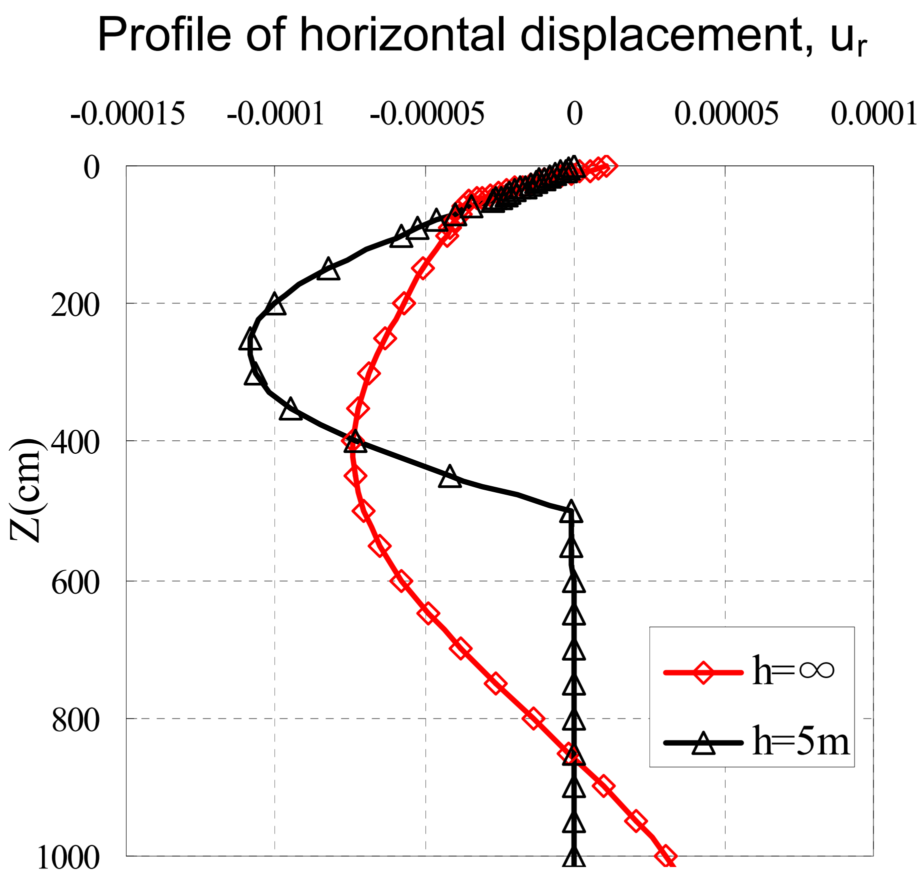


- Wave-Pave

(t=0.10s)

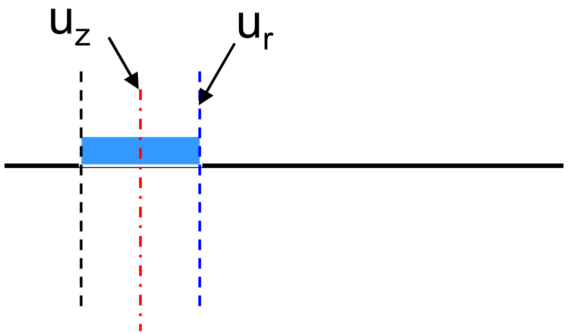


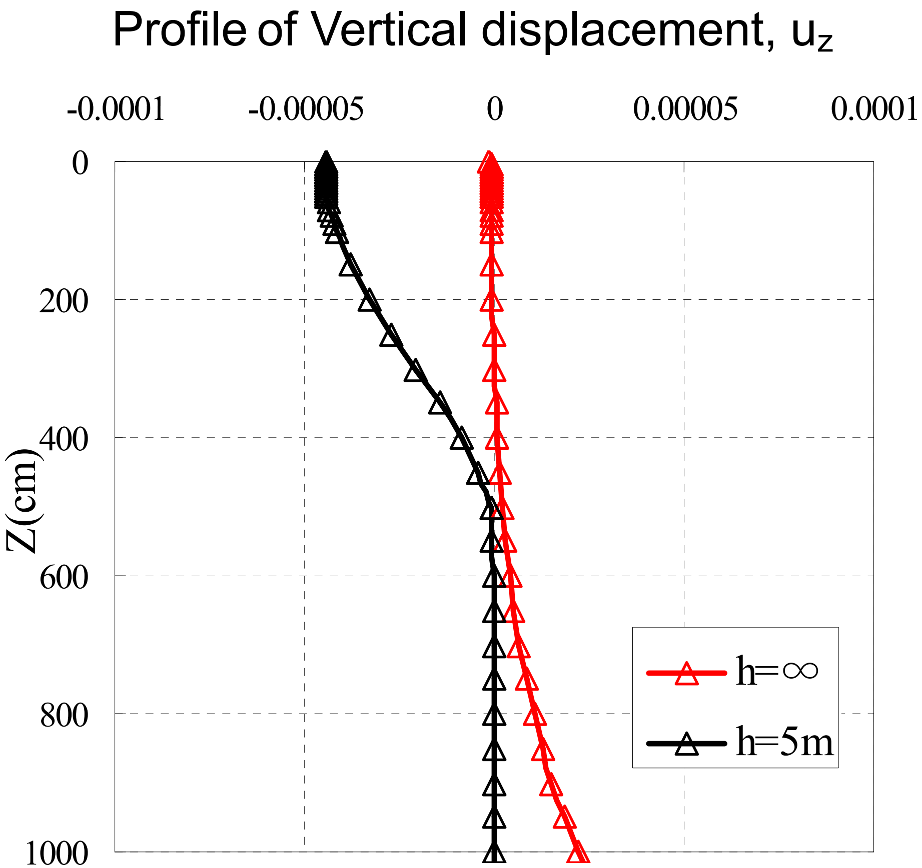


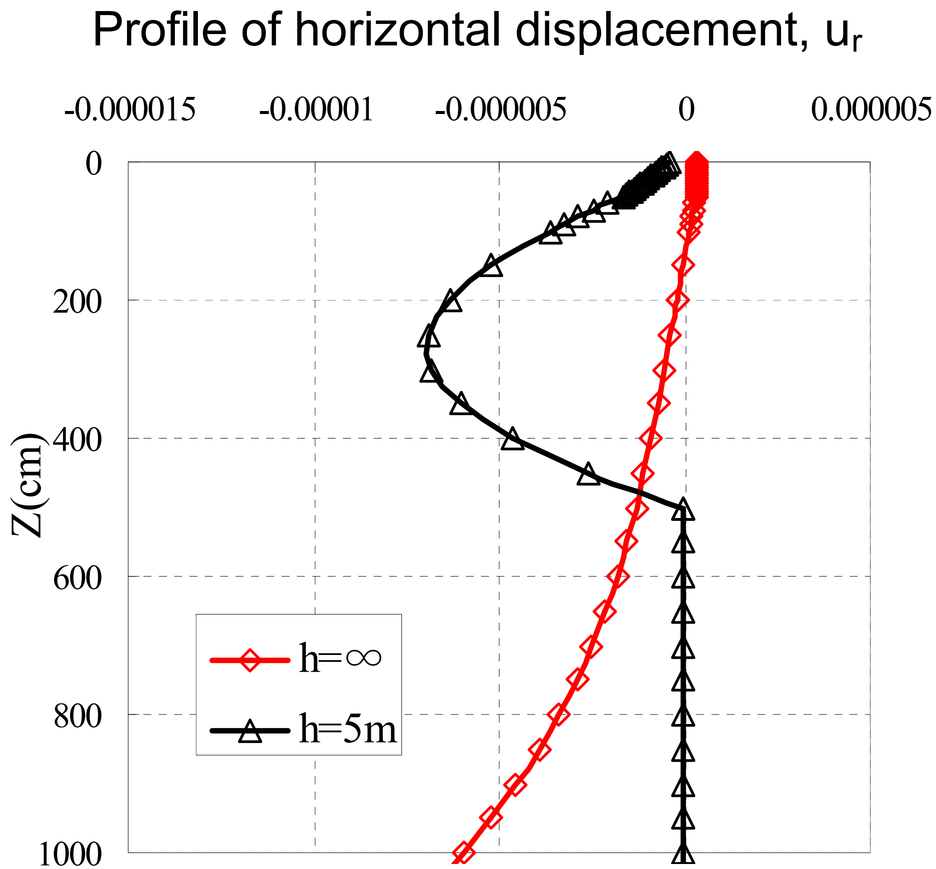


▪ Wave-Pave

(t=0.20s)







Dynamic Backcalculation

D-BALM (FEM)

W-BALM(Wave-Pave)

BALM: Static Backcalculation

Backcalculation

Objective Function

$$J = \frac{1}{2LN} \sum_{\ell=1}^{L} \int_{t0}^{t1} \sum_{i=1}^{N} \left\{ u_i^{(\ell)}(t) - z_i^{(\ell)}(\mathbf{X}, t) \right\}^2 dt$$

L : Number of tests

N : Number of sensors

$u_i^{(\ell)}$ Measured deflection at sensor *i* at (ℓ) th test

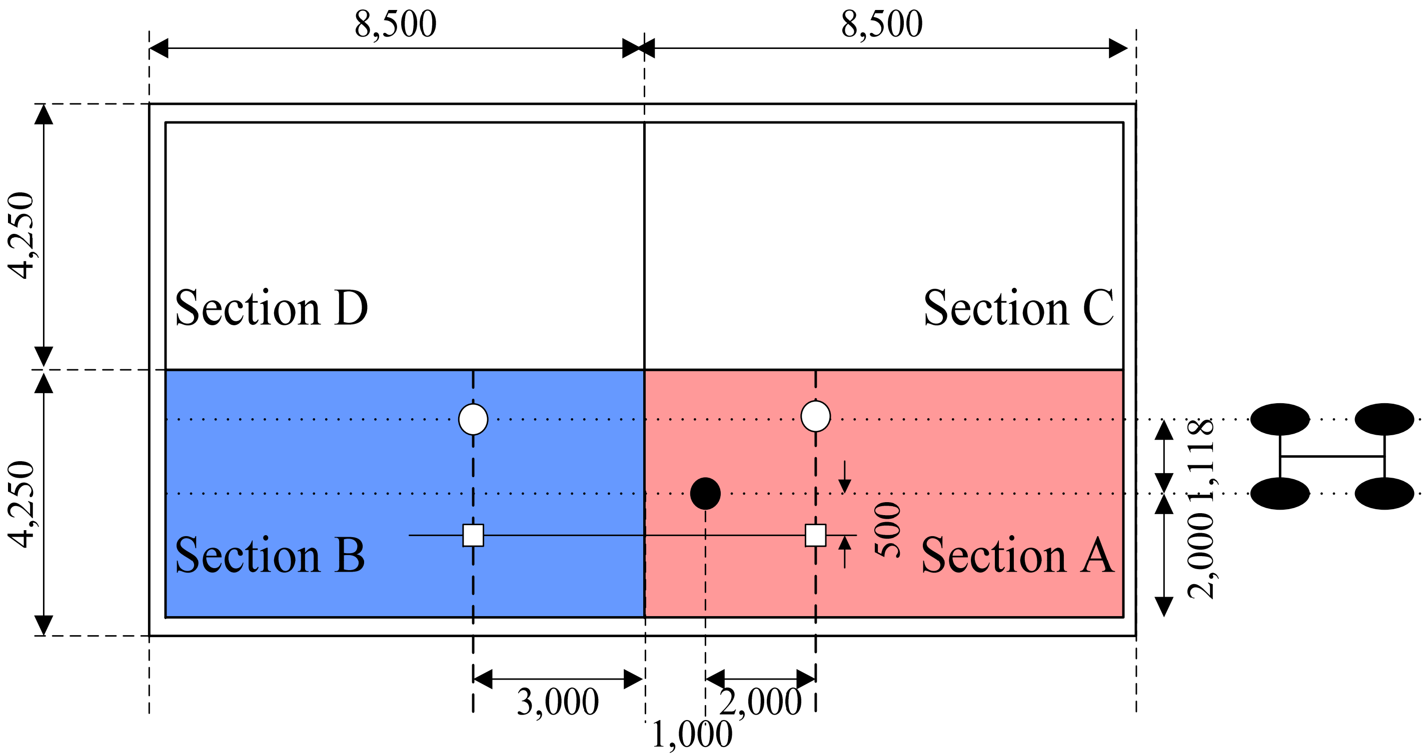
$\mathbf{X}$ Vector of unknown parameters

(layer modulus and layer damping)

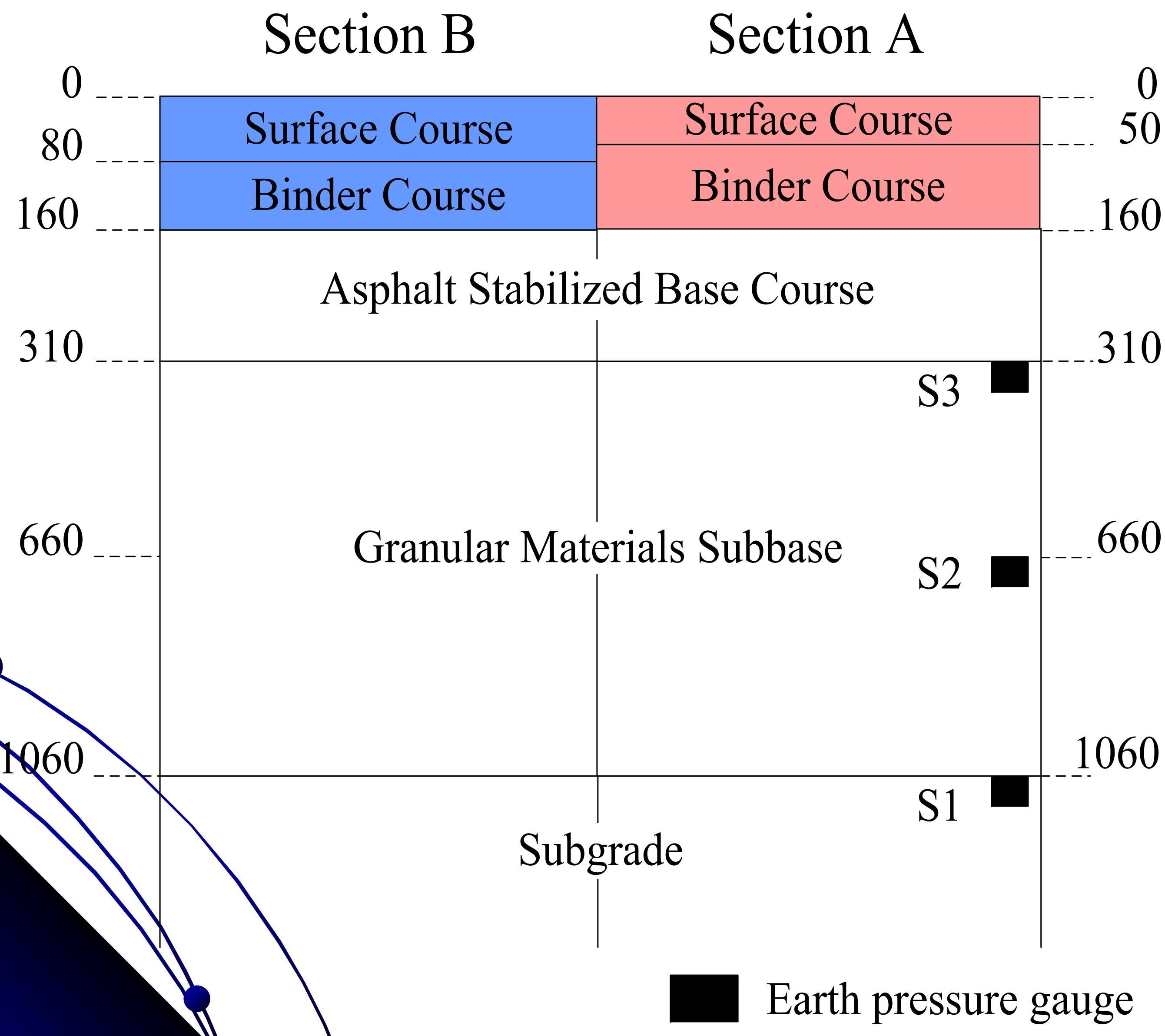
$(t0, t1)$ Time interval of deflection matching

National Institute for Land and Infrastructure Management (NILIM) in Japan

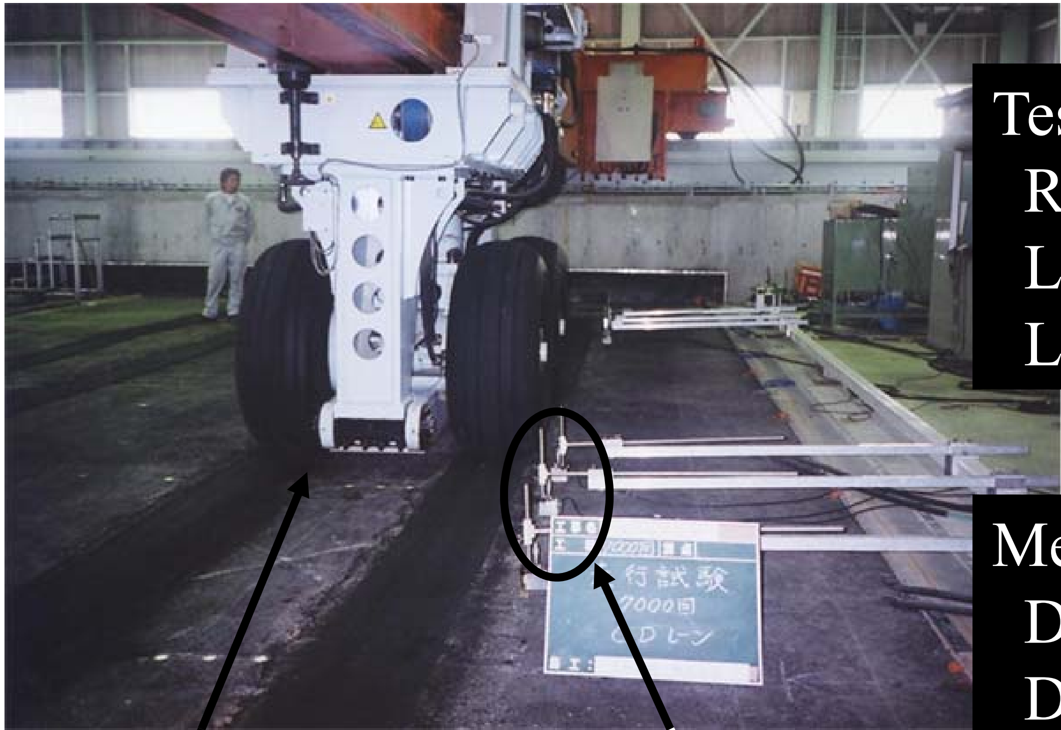
Same Size as Landing Gear of B747-400
Max. Running Speed : 5km/h
Max. Load : 1200kN



- ⋯⋯ Wheel path
- — — Measurement line of transverse surface profile
- ○ Loading plates of FWD and static loading test
- □ Displacement meter
- ● Earth pressure gauge



Section B
Section A
0
80
160
310
660
1060
0
50
160
310
660
1060
Surface Course
Binder Course
Surface Course
Binder Course
Asphalt Stabilized Base Course
Granular Materials Subbase
Subgrade
S3
S2
S1
Earth pressure gauge



Test Condition

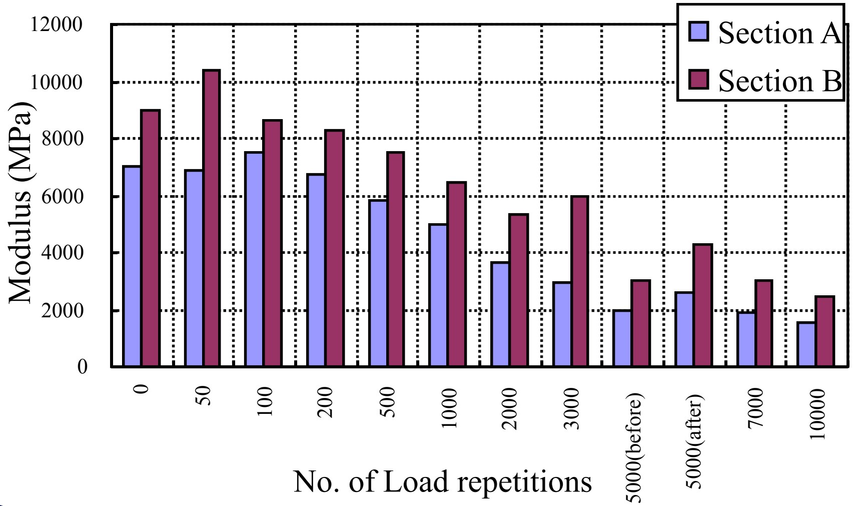
- Running Speed : 5km/h
- Load : 910kN
- Load Repetition : 10,000 times

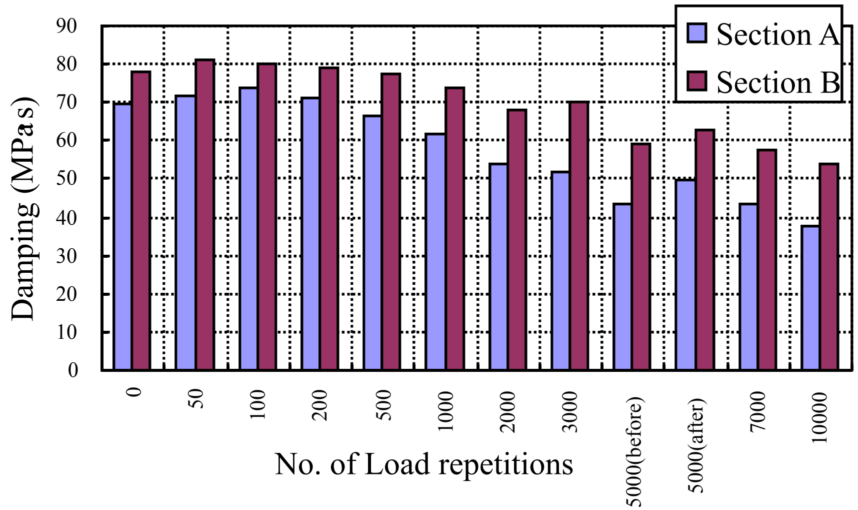
Measurement Item

- Dynamic Vertical Displacement
- Dynamic Soil Pressure

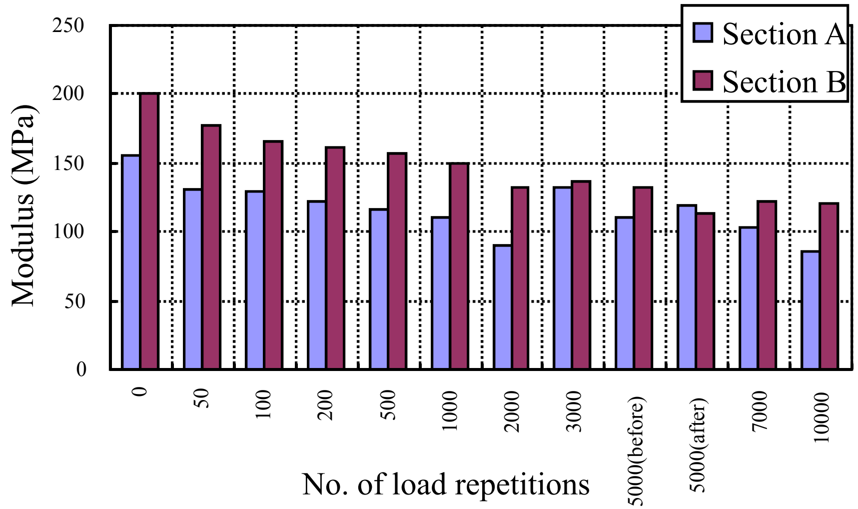
Aircraft Load Simulator

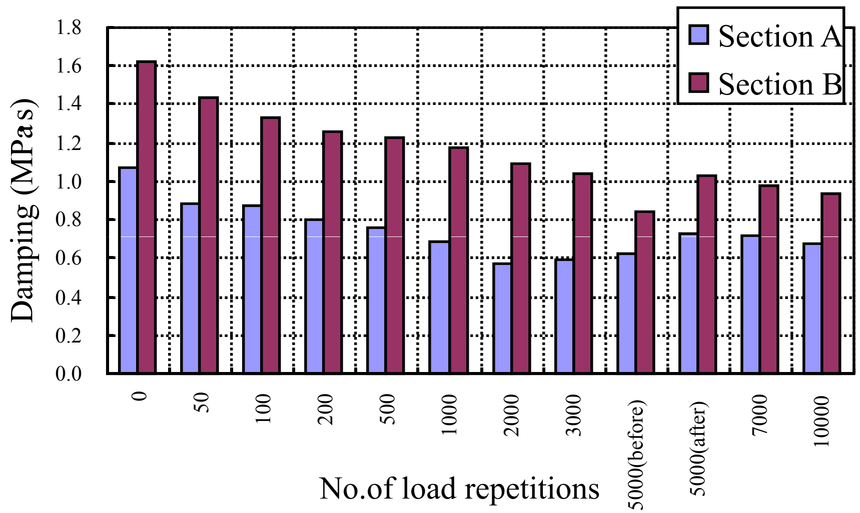
Backcalculated Results E1&C1



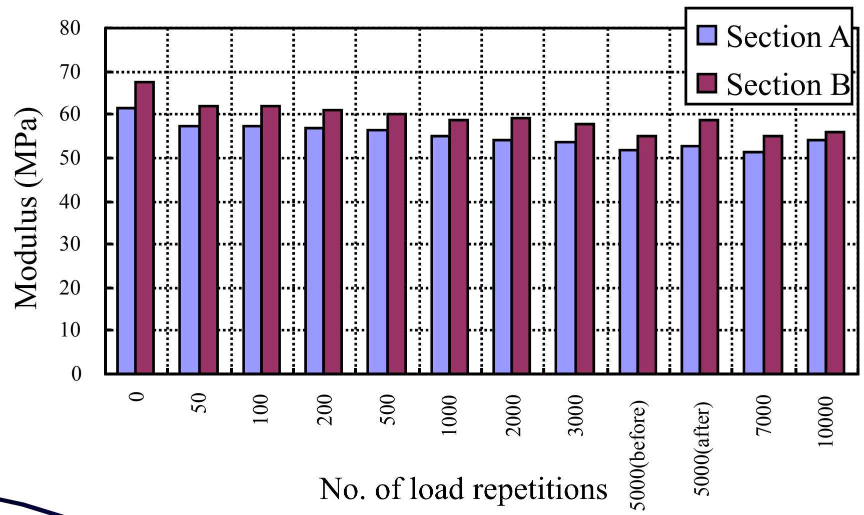


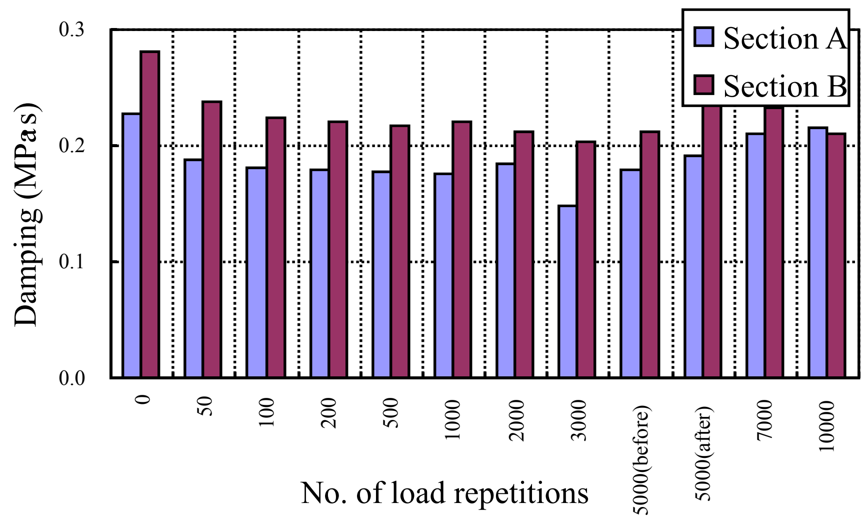
Backcalculated Results E2&C2





Backcalculated Results E3&C3

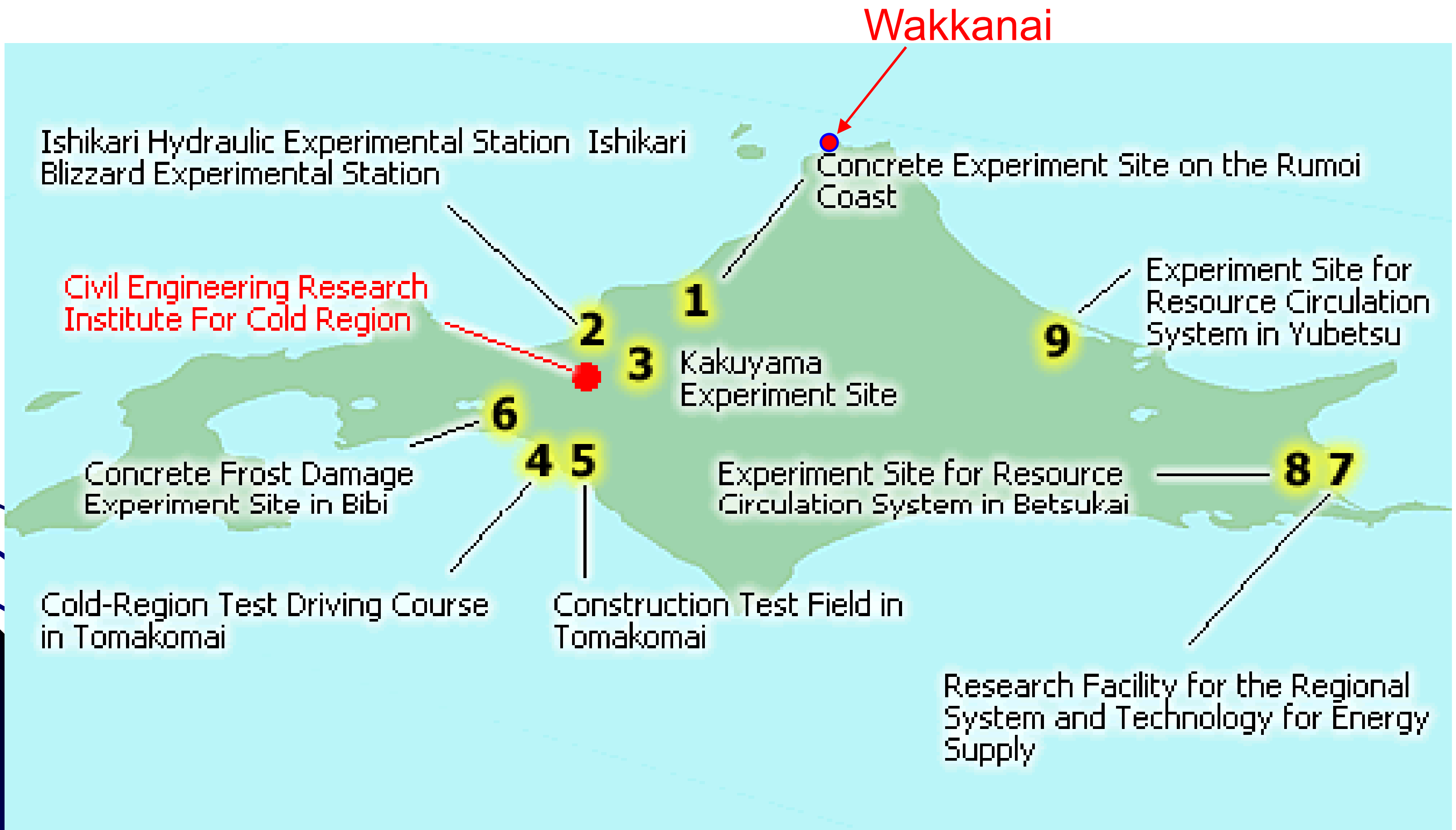




Incorporated Administrative Agency
Public Works Research Institute

Civil Engineering Research Institute for Cold Region (CERI)

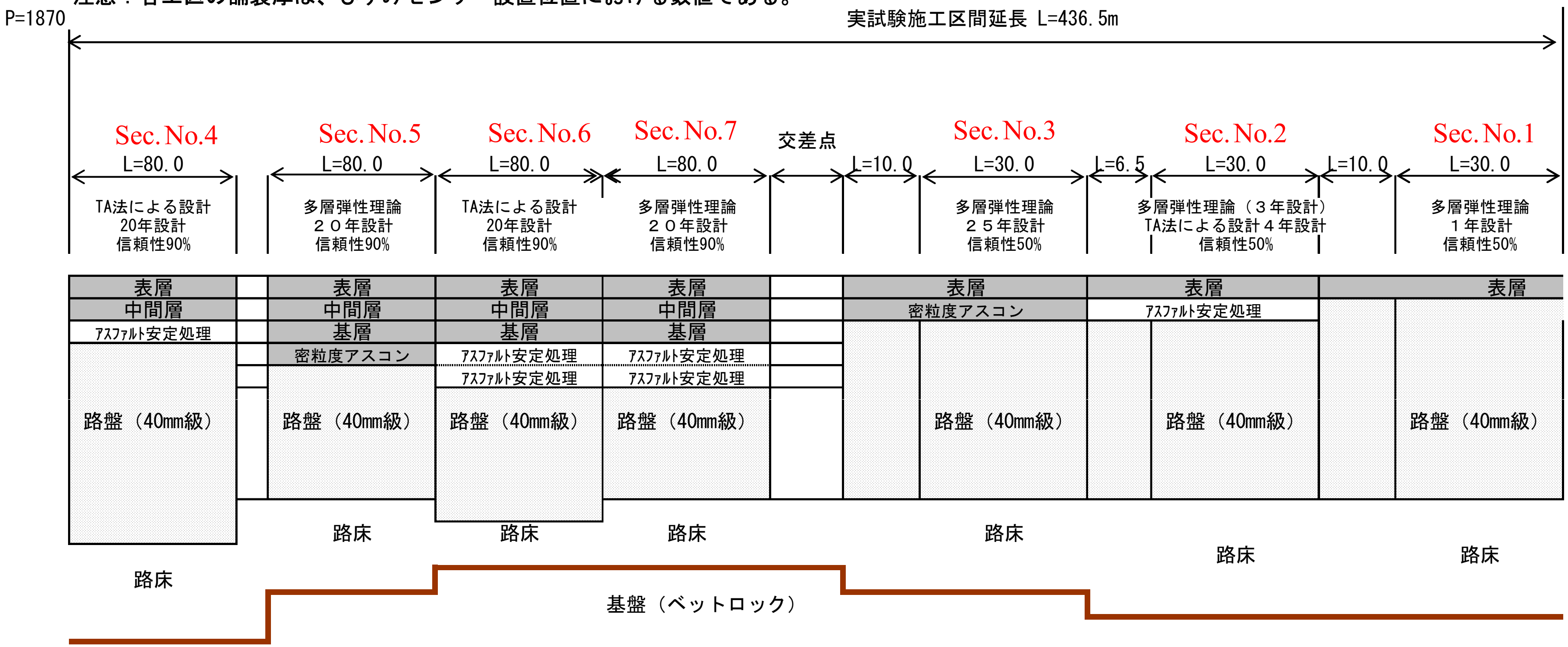
CERI Field Test Site



City of Wakkanai

Pavement Cross Sections

注意：各工区の舗装厚は、ひずみセンサー設置位置における数値である。



As層厚（cm）	16.0		23.0	32.3	32.5			11.1		10.7		10.3
路盤厚（cm）	100.0		62.6	52.7	51.5			70.9		77.3		72.7
路床厚（cm）	275.0		200.0	154.0	140.0			190.0		210.0		210.0
ベットロック	岩盤（風化泥岩）											
舗装厚	116.0		85.6	85.0	84.0			82.0		88.0		83.0

測点	P=1870～1950		P=2080～2160	P=2160～2240	P=2240～2320		P=2483.5～2493.5	P=2493.5～2523.5	P=2523.5～2530	P=2530～2560	P=2560～2570	P=2570～2600
延長	L=80		L=80	L=80	L=80		L=10	L=30	L=6.5	L=30	L=10	L=30

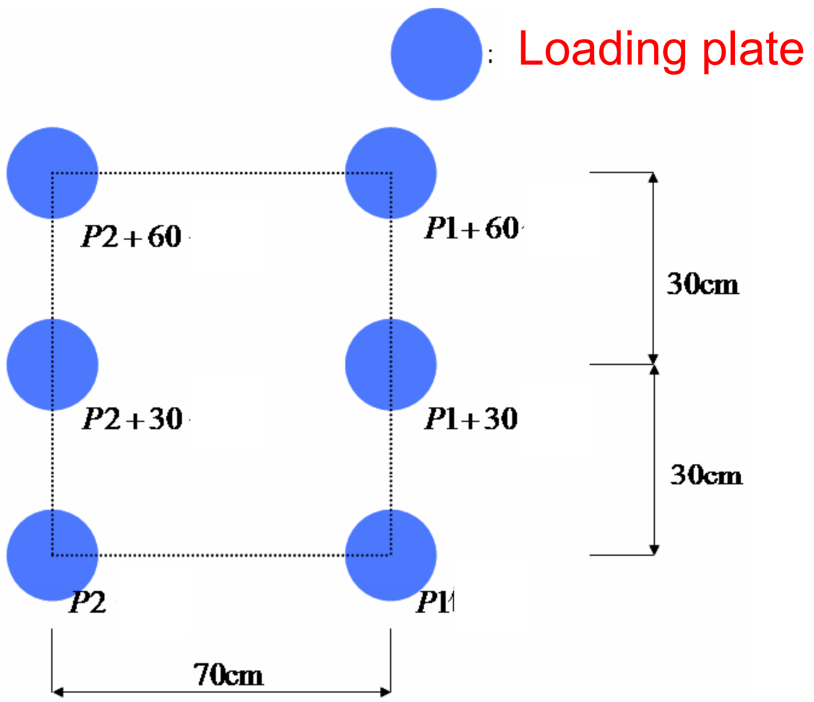
※As層厚および路盤厚は、㈱ウオールナットさんの実測値を使用した。　ただし、センサー設置位置は路盤上部が多少下がっていると予想して、路線調査におけるセンサー設置測点の舗装厚から、センサー位置JustにおけるAs層厚を差し引いたものを路盤厚とした。
※路床厚は調査で測定できなかったことから、従来どおり地質断面図から推定した。

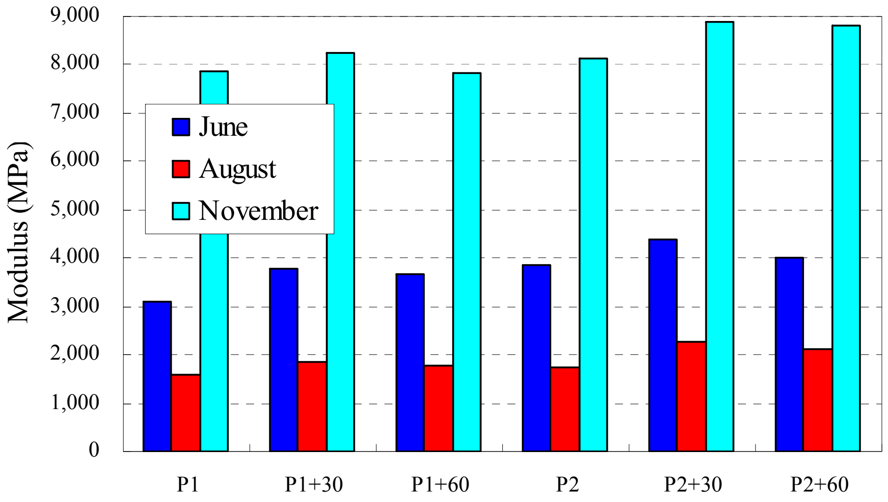
FWD Test

National highway 238 (test site)

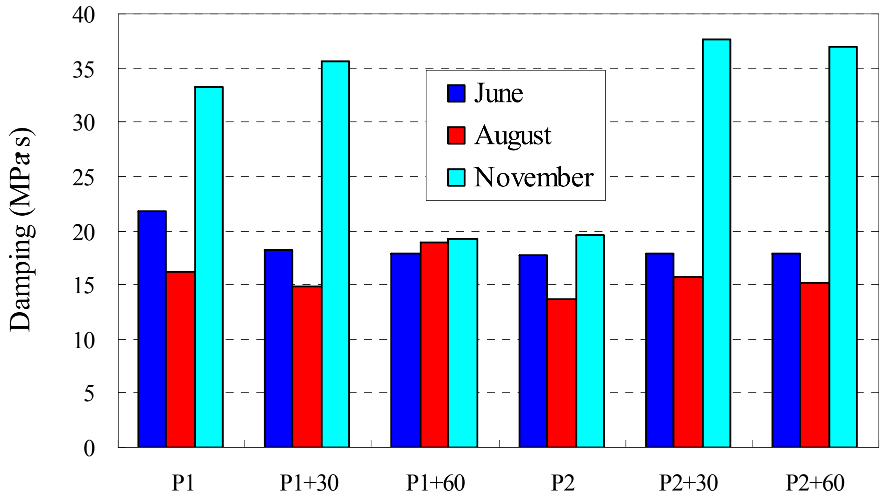
Truck Loading Test

Position of FWD Loading Plate

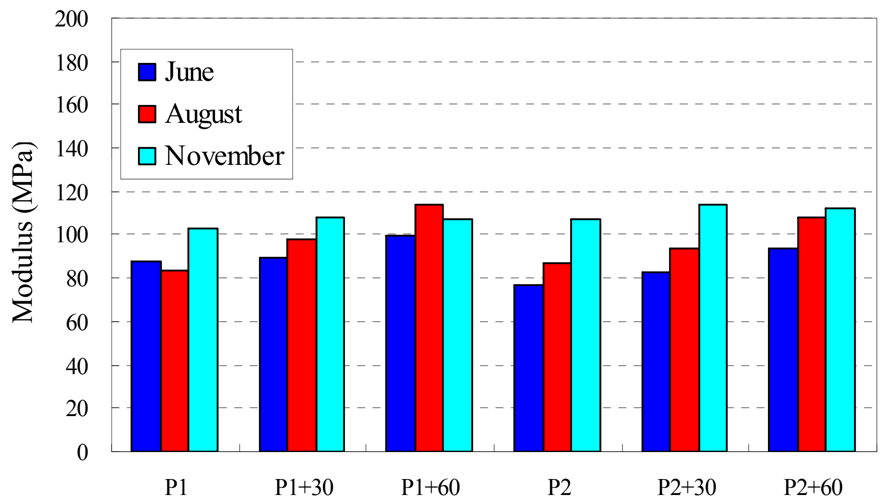




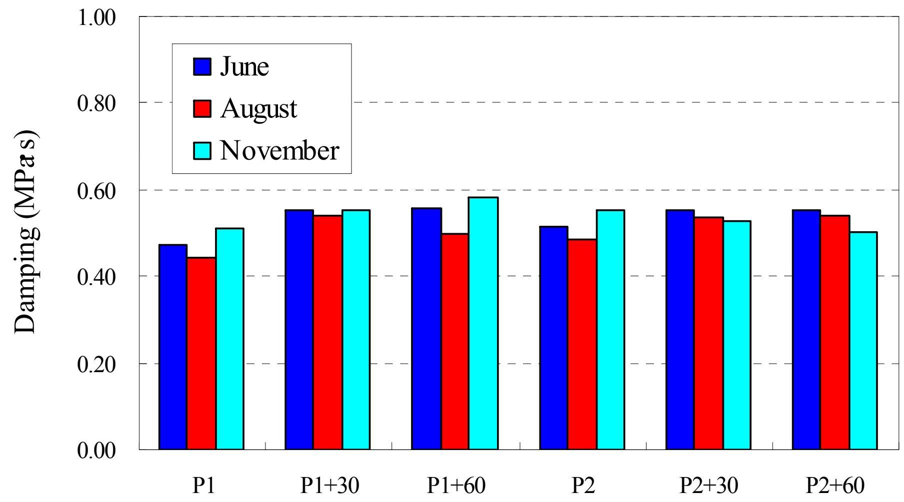
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Modulus (MPa)
June
August
November
P1
P1+30
P1+60
P2
P2+30
P2+60



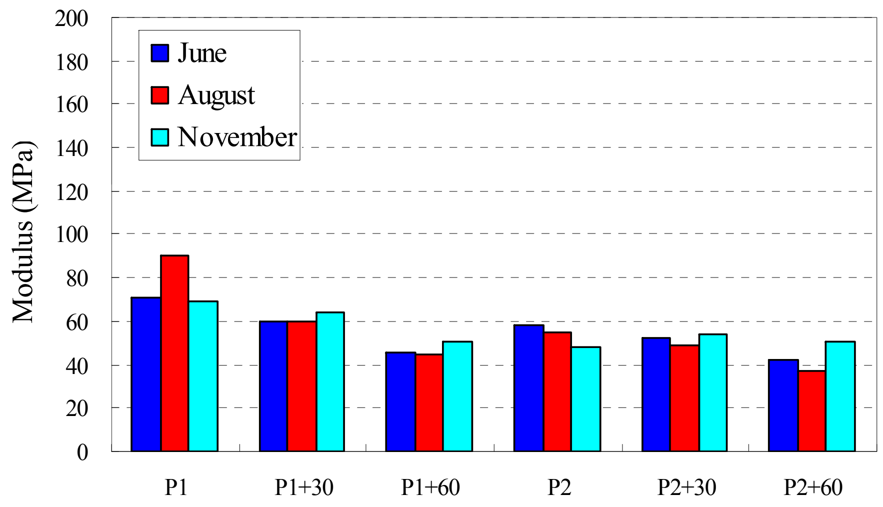
40
35
30
25
20
15
10
5
0
Damping (MPa s)
June
August
November
P1
P1+30
P1+60
P2
P2+30
P2+60

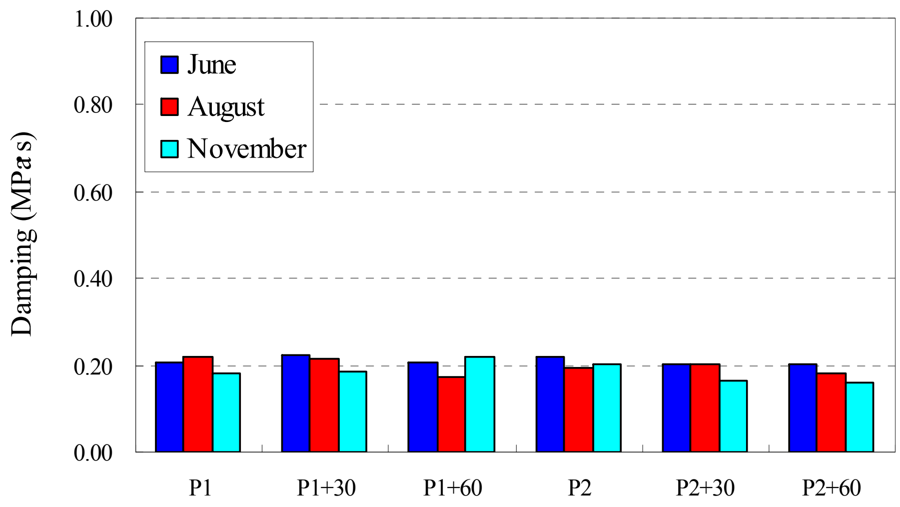


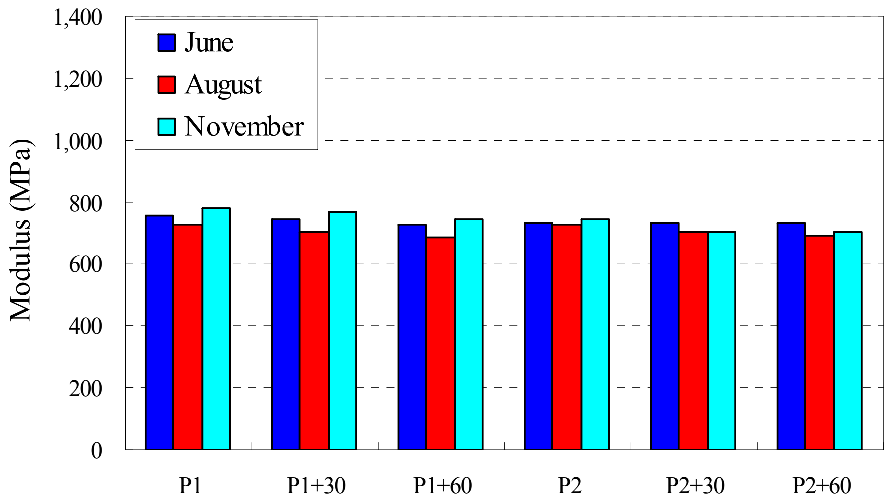
200
180
160
140
120
100
80
60
40
20
0
Modulus (MPa)
June
August
November
P1
P1+30
P1+60
P2
P2+30
P2+60

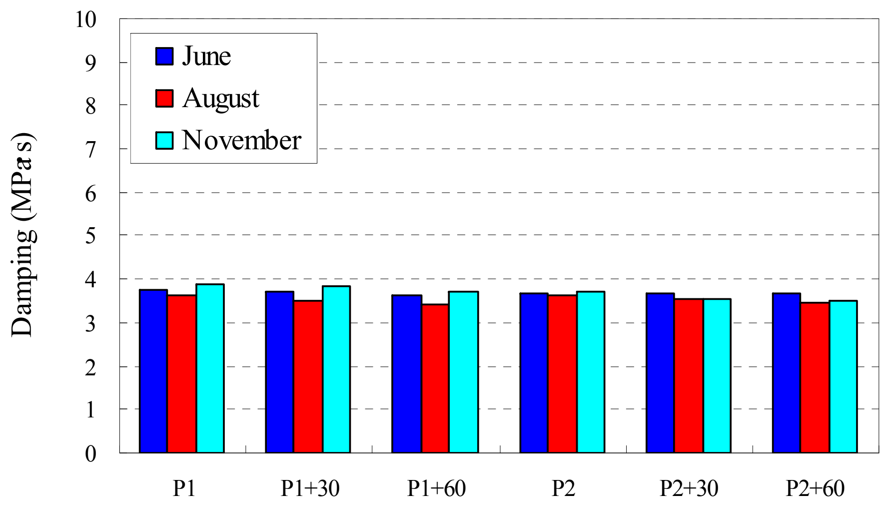


1.00
0.80
0.60
0.40
0.20
0.00
Damping (MPa s)
June
August
November
P1
P1+30
P1+60
P2
P2+30
P2+60


June
August
November
Modulus (MPa)
200
180
160
140
120
100
80
60
40
20
0
P1
P1+30
P1+60
P2
P2+30
P2+60

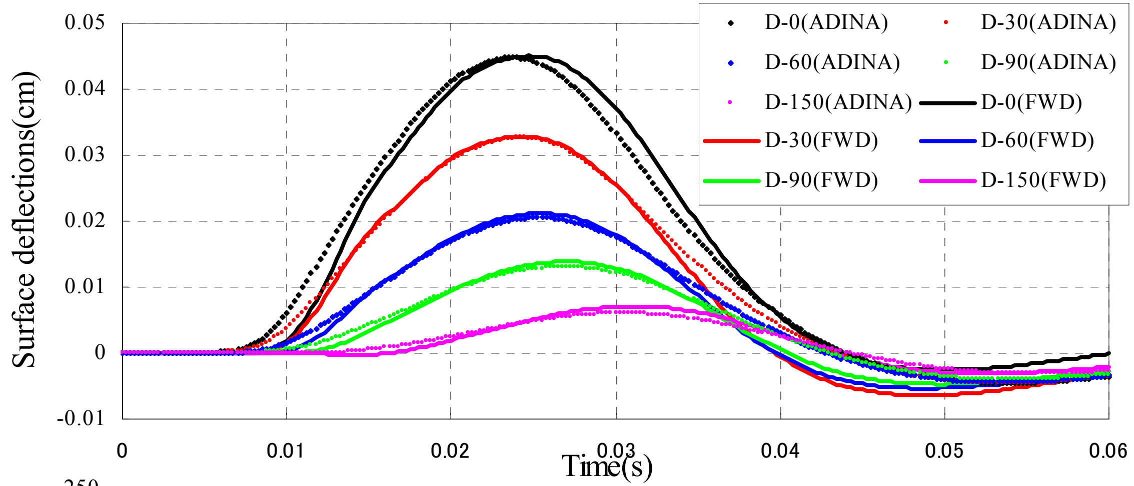

June
August
November
Damping (MPa s)
1.00
0.80
0.60
0.40
0.20
0.00
P1
P1+30
P1+60
P2
P2+30
P2+60

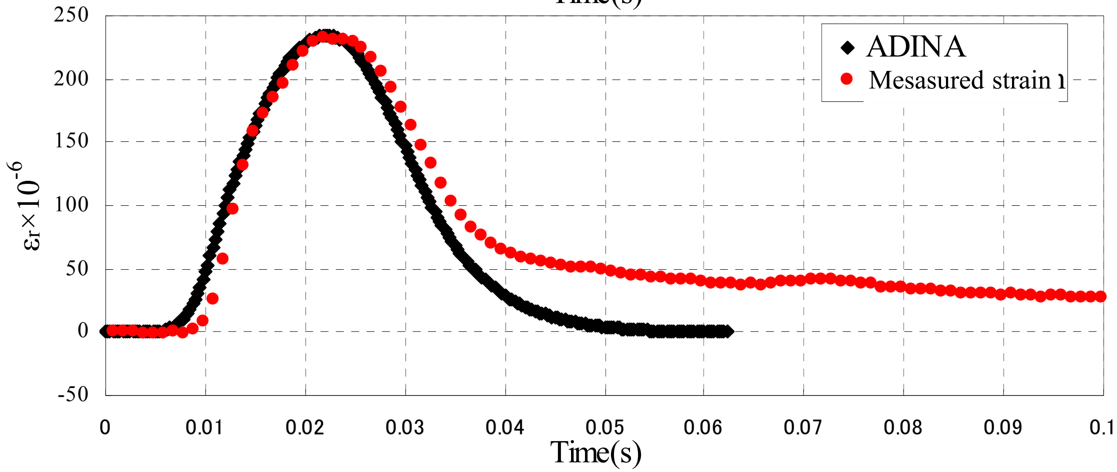

June
August
November
Modulus (MPa)
1,400
1,200
1,000
800
600
400
200
0
P1
P1+30
P1+60
P2
P2+30
P2+60

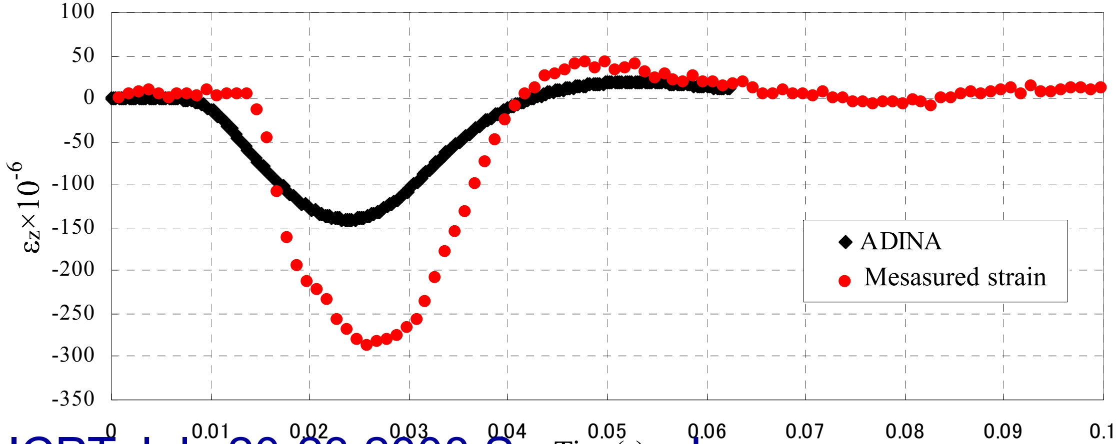

June
August
November
Damping (MPa s)
10
9
8
7
6
5
4
3
2
1
0
P1
P1+30
P1+60
P2
P2+30
P2+60

Back-Calculation

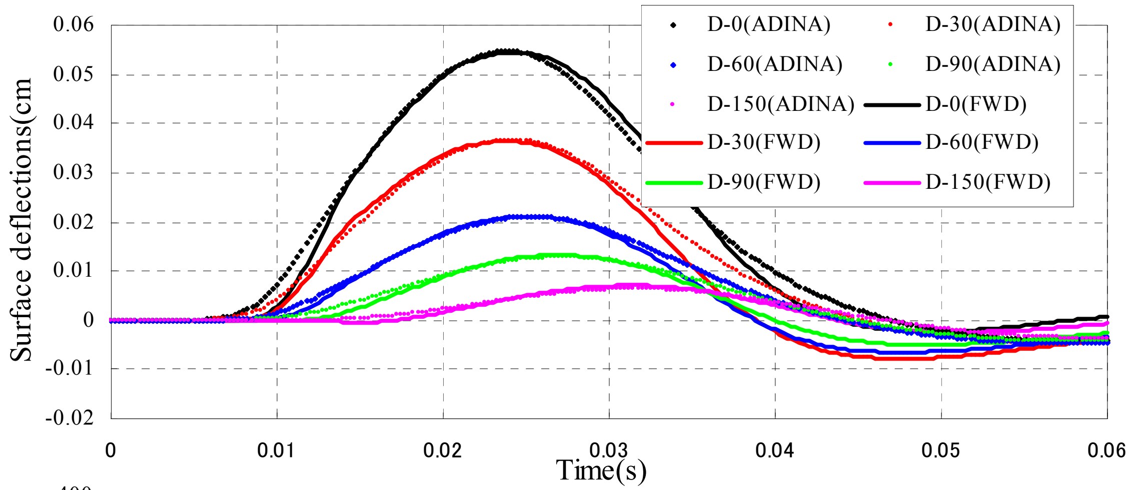
June 2006



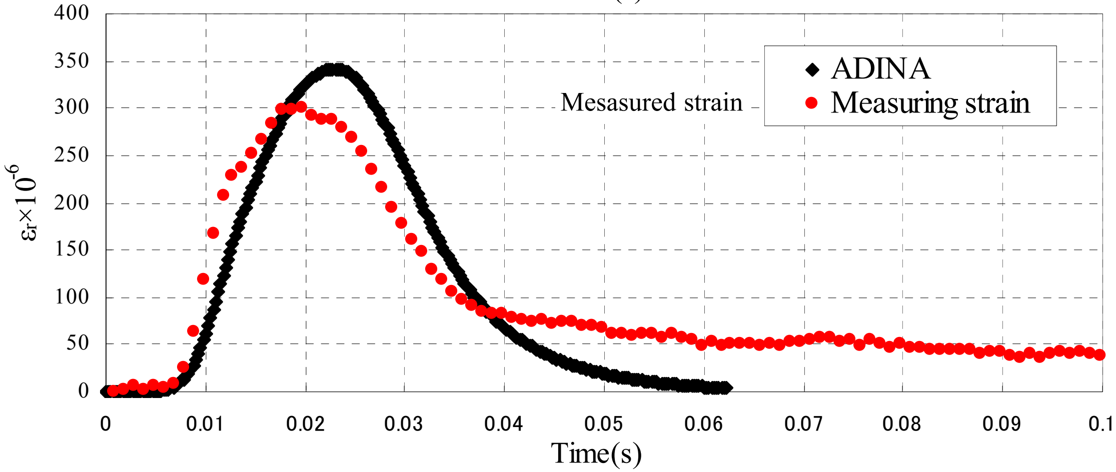




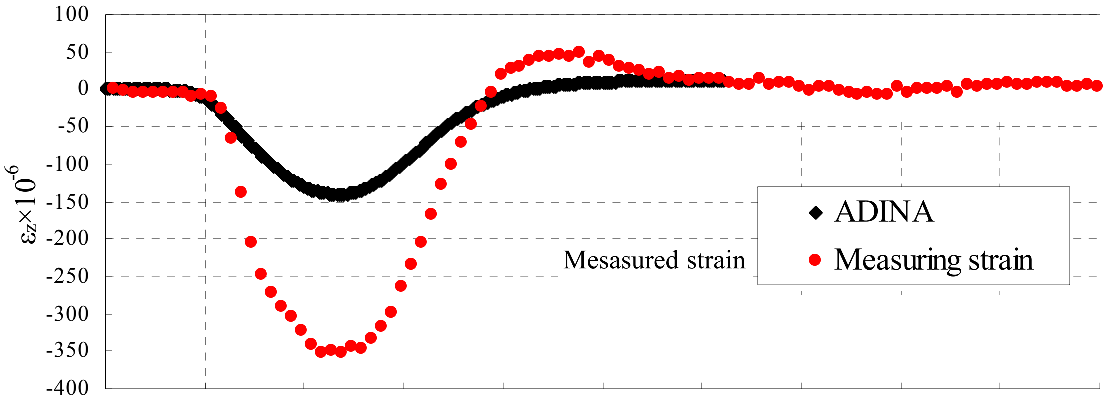
August 2006



Surface deflections(cm
Time(s)
D-0(ADINA)
D-30(ADINA)
D-60(ADINA)
D-90(ADINA)
D-150(ADINA)
D-0(FWD)
D-30(FWD)
D-60(FWD)
D-90(FWD)
D-150(FWD)
0.06
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
0
0.01
0.02
0.03
0.04
0.05
0.06

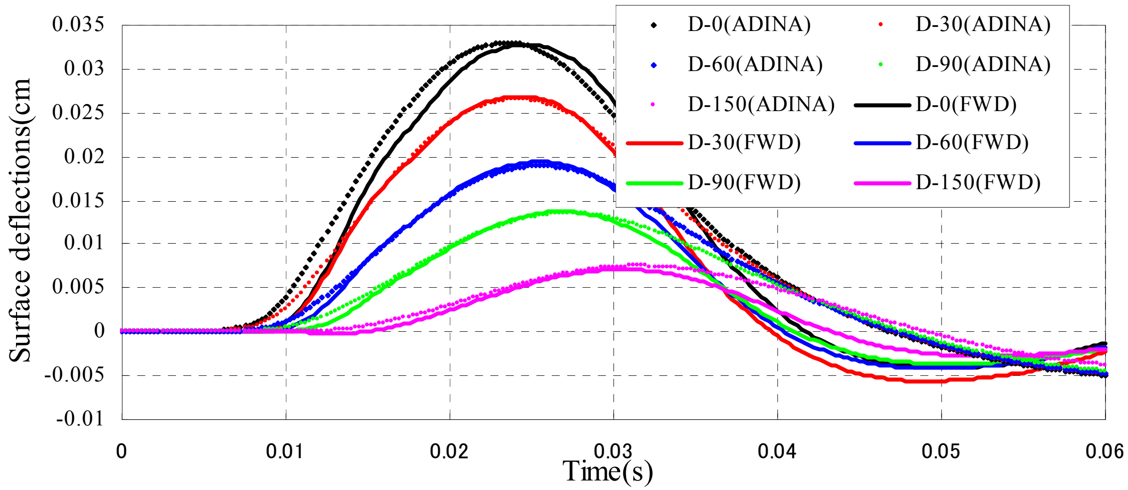


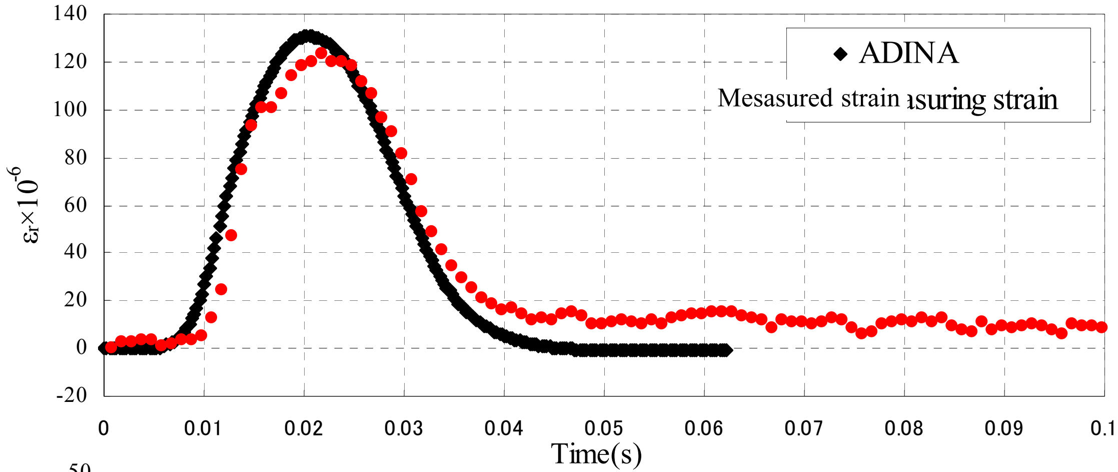
εr×10^-6
Time(s)
Mesasured strain
ADINA
Measuring strain
400
350
300
250
200
150
100
50
0
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1

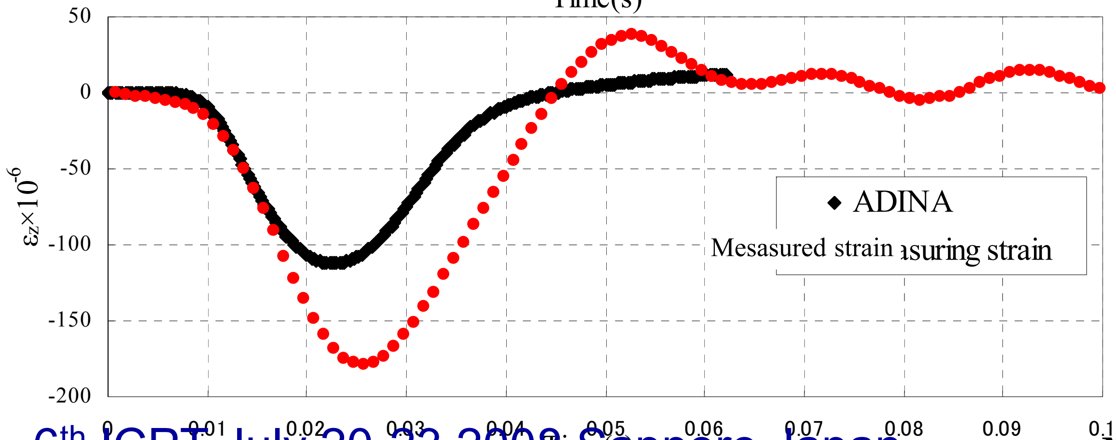


εz×10^-6
Mesasured strain
ADINA
Measuring strain
100
50
0
-50
-100
-150
-200
-250
-300
-350
-400
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1

November 2006







Questions ?

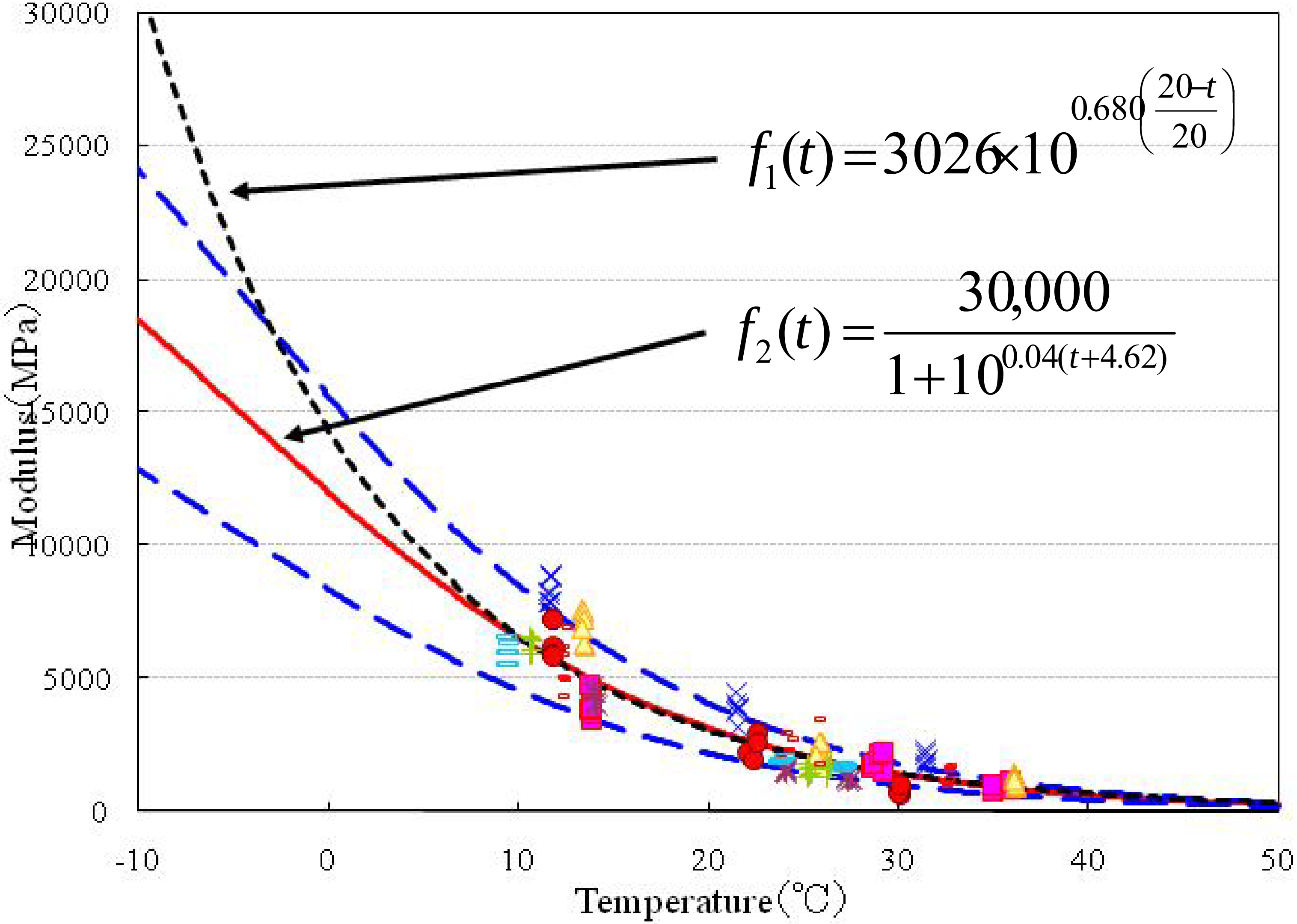
GAMES can be downloaded from

http://www.jsce.or.jp/committee/pavement/downloads/

http://matsui.labo.googlepages.com/games_win.eng

Thank you !

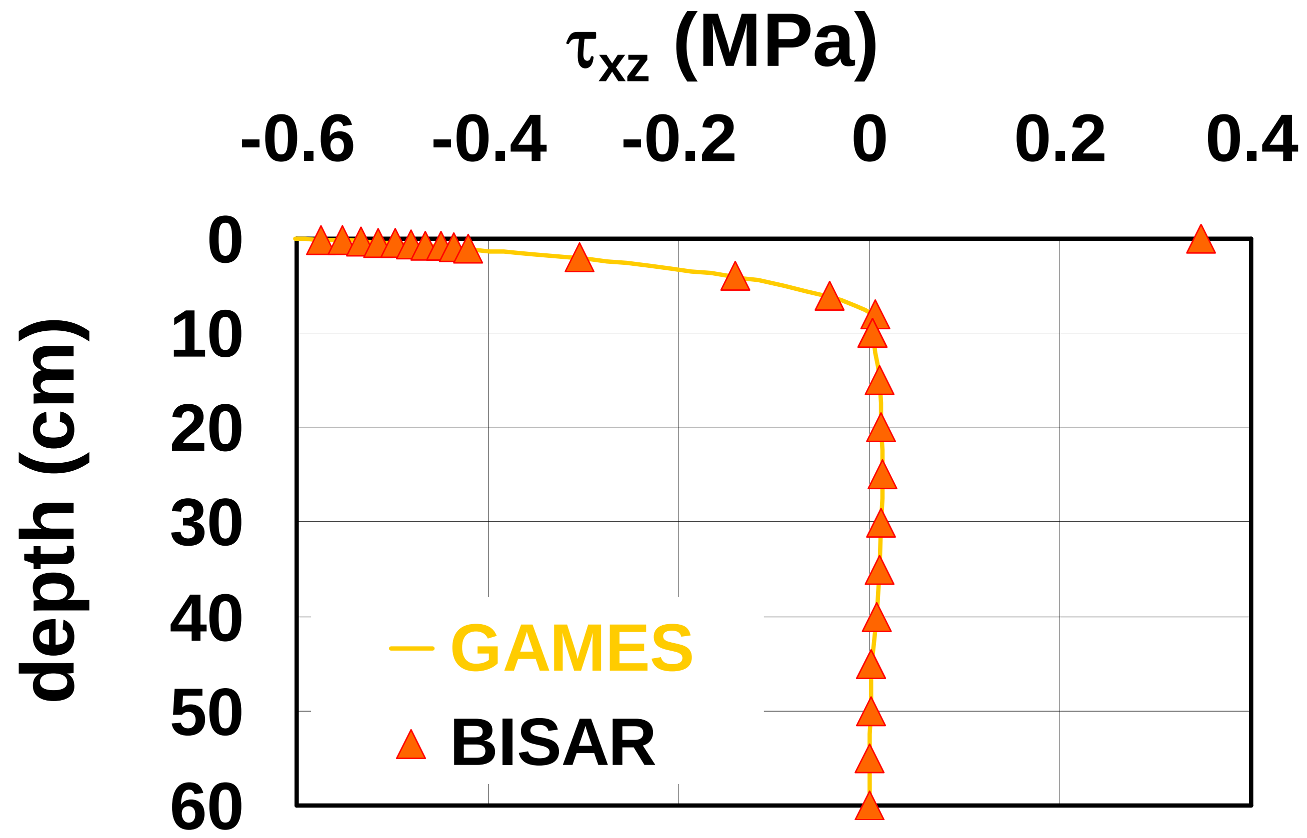
Pavement Profiles



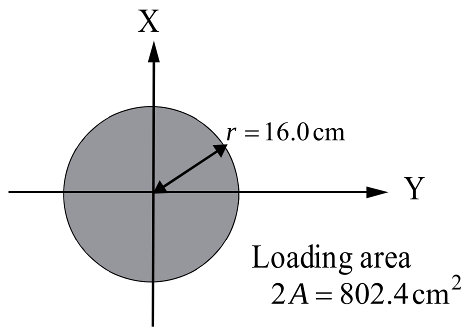
1. Static Analysis

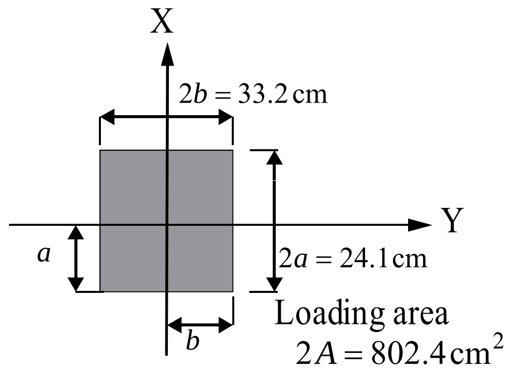
GAMES vs BISAR

~ Distribution of shearing stress, t_{xz} ~



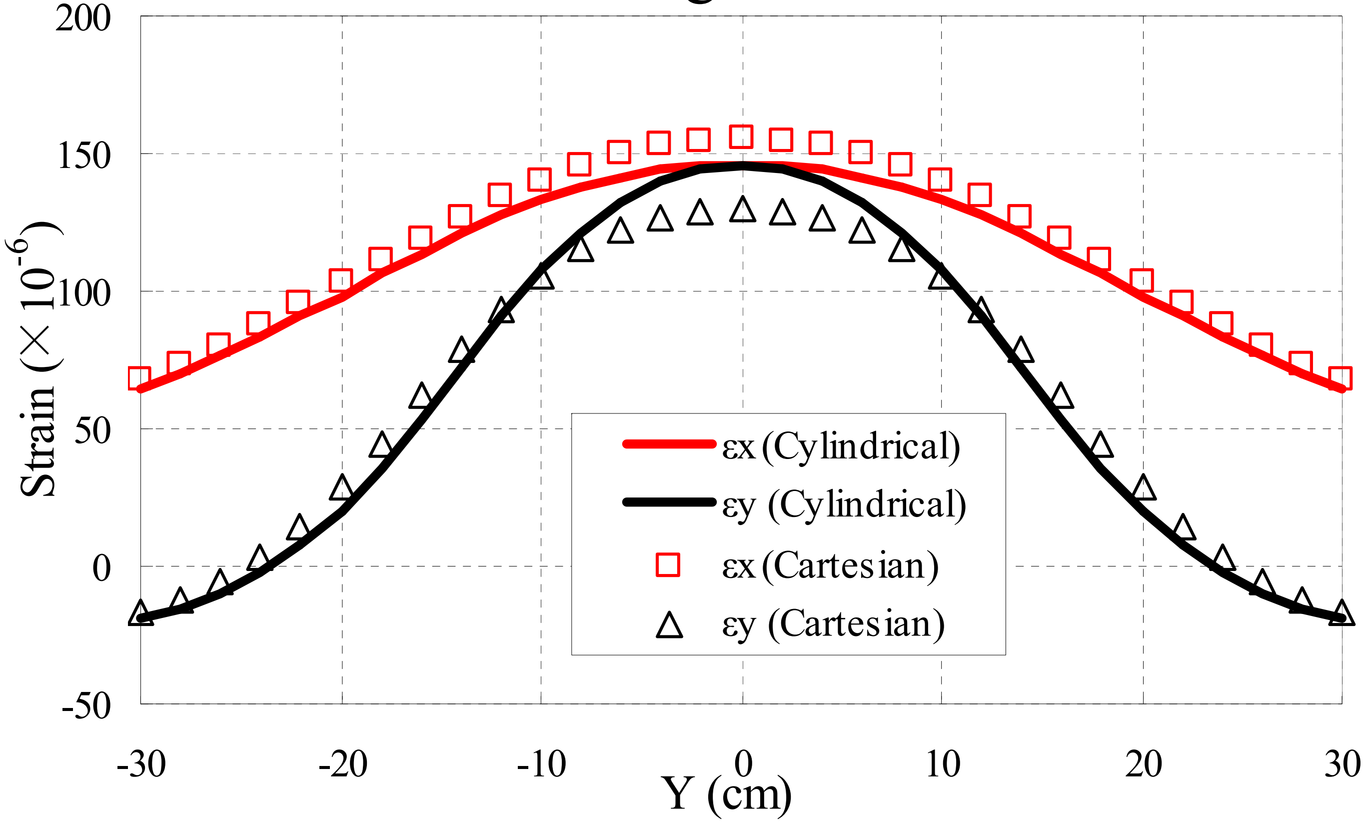
1. Static Analysis



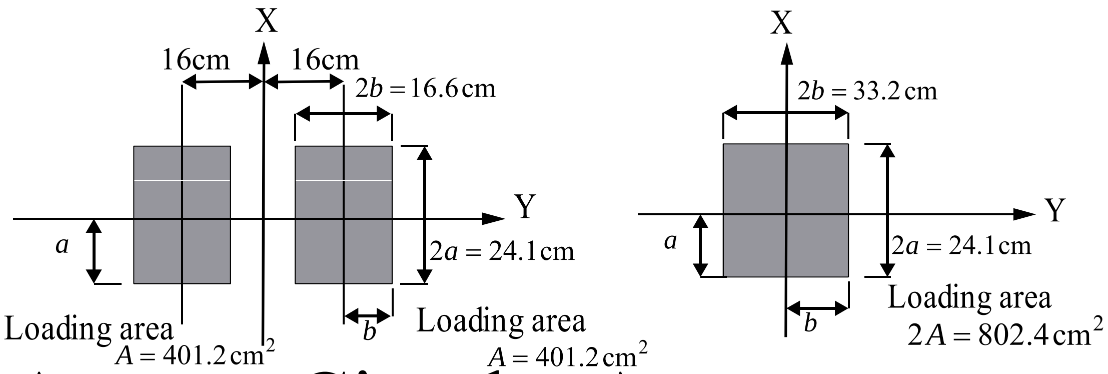


Rectangular Area vs Circular Area

~ Single tires ~

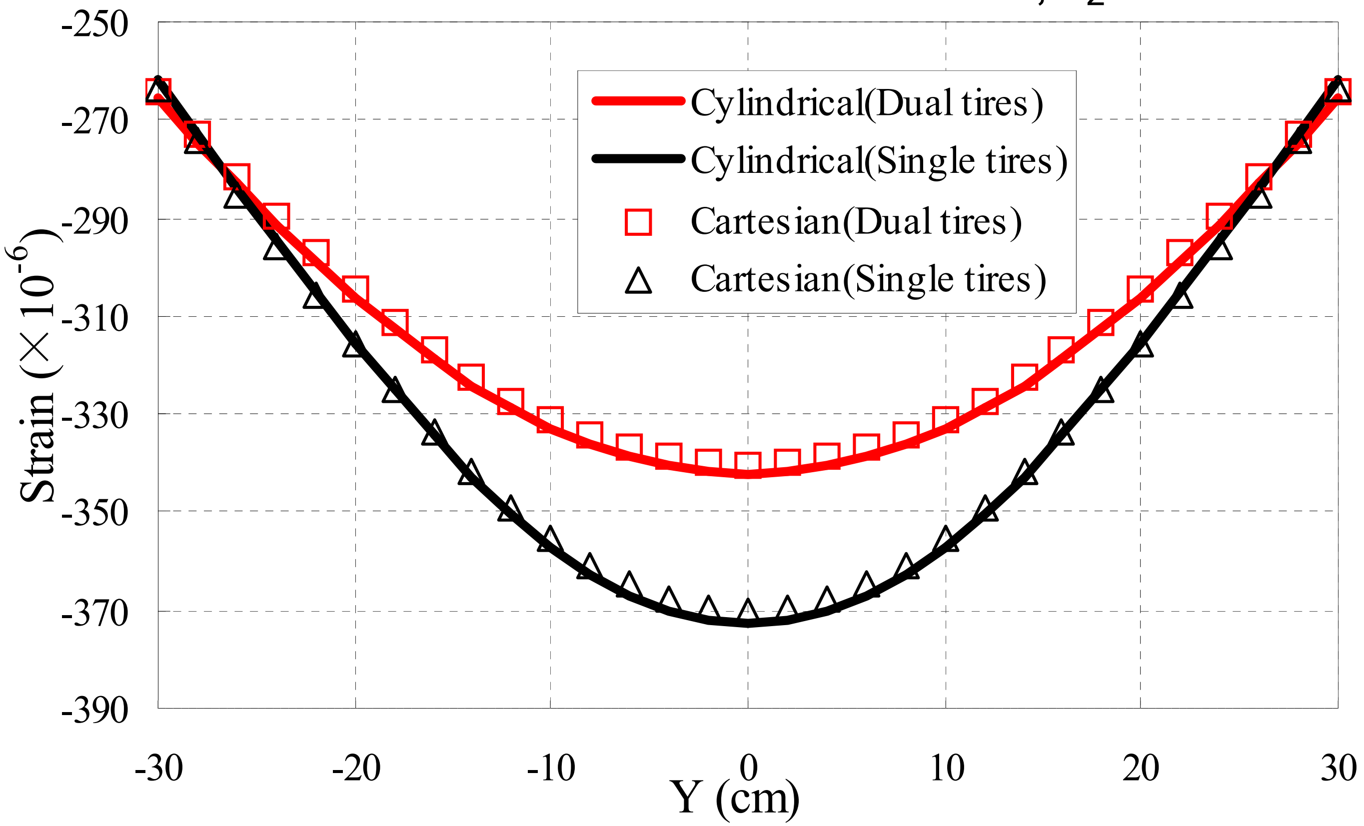


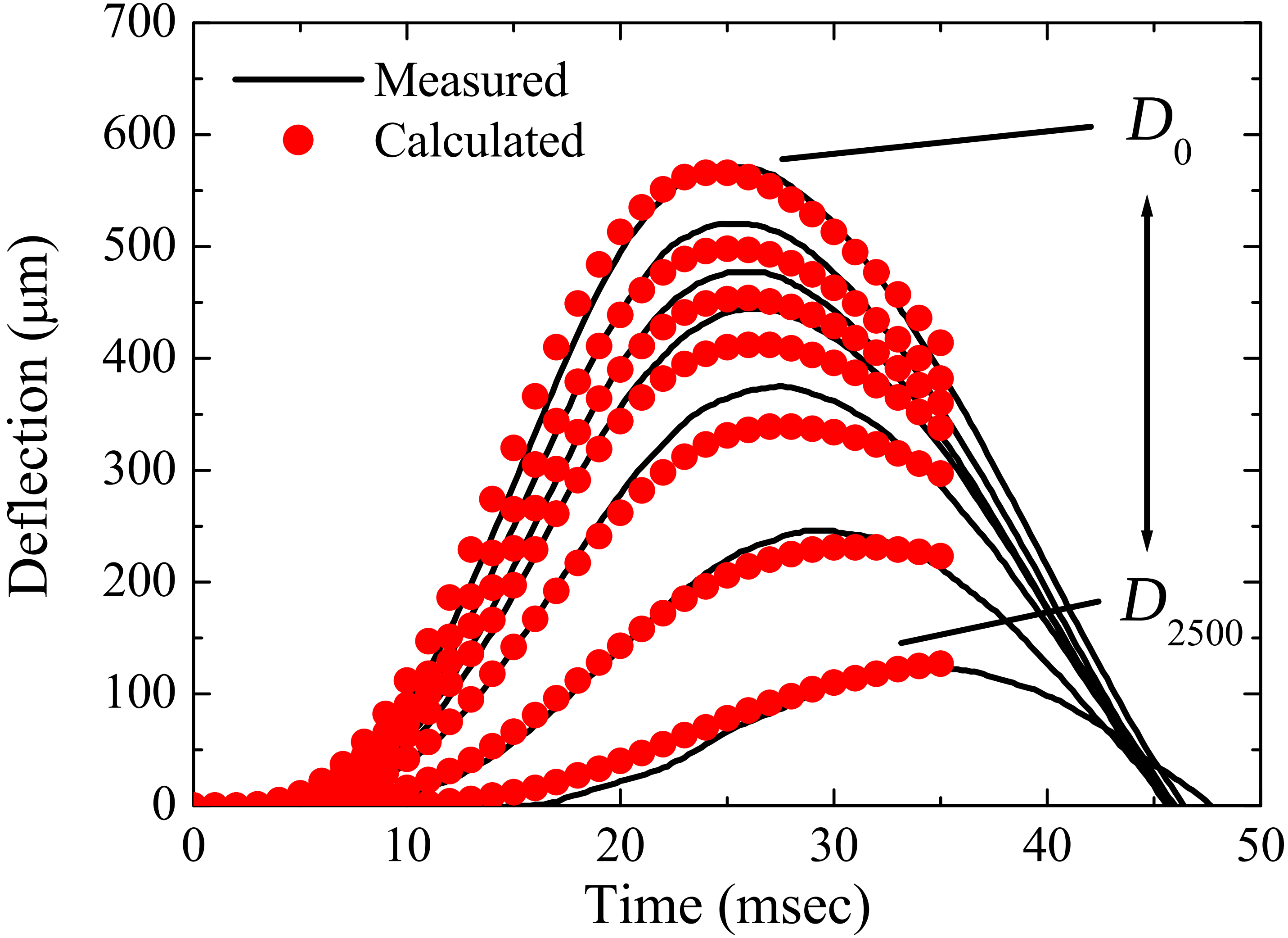
1. Static Analysis



Rectangular Area vs Circular Area

~ Distribution of Vertical strain, ε_z ~





Dynamic Back-calculation using FWD Deflection Data